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FURTHER DEVELOPMENT AND TESTING OF AN END-OF-TRAIN MONITORING SYSTEM

Prepared for the
Transportation Development Centre
of Transport Canada

by

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Un sommaire en français de ce rapport est inclus avant la Table des matières.

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17. Abstract

This report describes further development of the Digitair end-of-train telemetry system. A number of new features have been designed and successfully field-proven: an odometer for the head end; a motion detector which displays the direction of start, moving/stopped status, and buff/draft condition of the rear car; software compatible with the Association of American Railroads (AAR) guidelines; a Highly Visible Marker light integral with the rear unit; and an optional version of the rear unit which can sense and transmit a second pressure.

The original system, with the addition of some of these features, was found satisfactory by the U.S. railways. However the Canadian railways have been required by the Canadian Transport Commission to test a telemetry system which also has the capability to apply the emergency brake at the rear of the train on command from the front. A specification describing such a system was therefore formulated with input from Canadian National and Canadian Pacific railways. Because addition of braking capability meant adding a second (front-to-rear) communication link, essentially a redesign of the whole system was undertaken. This new two-way system, Digitair II, has shown excellent performance in tests done by CN, with communication success rates better than 98% over a variety of terrain and train lengths, and with emergency brake reliability of 100%. The new system is rated to -45 degrees C.

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17. Résumé

Ce rapport décrit les travaux de mise au point du système de surveillance en queue de train appelé Digitair. Ce système comporte de nouvelles fonctions qui ont été éprouvées avec succès, à savoir: mesurage de la distance parcourue (odomètre) ajoutée au module avant; détection de rotation des roues du dernier wagon avec indication des paramètres de rotation, arrêt, dernier wagon en traction ou en compression; programme informatique conforme à la procédure de transmission adoptée par l'Association of American Railroads; feu arrière à forte intensité lumineuse intégré au module arrière et, en facultatif, contrôle de deux circuits.

Le nouveau système incorporant quelques-unes desdites fonctions a été jugé acceptable par la FRA des Etats-Unis. Toutefois, au Canada, la Commission canadienne des transports a exigé des sociétés ferroviaires qu'elles essayent un module arrière capable d'actionner le freinage d'urgence sur un signal radio transmis par le module avant. La spécification de ce module a été rédigée de concert avec le CN et le CP. Cette prescription, entraînant la mise en place d'une deuxième liaison (de l'avant vers l'arrière), a nécessité une réétude presque totale du système dans son ensemble, débouchant sur un nouveau système appelé Digitair II. Celui-ci a été soumis par le CN à des essais de transmission réussis: les taux de réussite ayant dépassé les 98 % sur divers types de terrains et à l'égard de convois de longueur variable, tandis que le taux de réussite en freinage d'urgence a été de 100 %. Ce matériel peut fonctionner malgré des températures tombant à - 45°C.

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SUMMARY

1. INTRODUCTION

In 1984 a reliable, high performance telemetry system, Digitair, was developed to relay information from the rear end of a freight train to its leading locomotive. This work was funded in part by the Transportation Development Centre (TDC) of Transport Canada, and is reported in TDC publication TP6057E, titled "End-of-Train Monitoring System", by R. J. Pomeroy, November 1984. At that time a number of additional features were identified as being necessary or desirable to implement cabooseless operation. They are:

- An accurate distance measuring device (odometer) to allow the engineman to know when the tail end has cleared a wayside location, such as an at-grade crossing or switch.
- A motion sensor to detect movement of the rear car.
- Capability to detect buffing and drafting of the rear car.
- Compliance with the Guidelines of the Association of American Railroads (AAR) for end-of-train telemetry devices.
- A Highly Visible Marker (HVM) light integral with the rear equipment to mark the last car.
- Capability of monitoring and transmitting a second pressure from the rear unit.

Accordingly, a second contract was awarded Glenayre Electronics Ltd. by TDC in July 1984 to: develop these features; in consultation with the Canadian railways, develop a specification for such equipment to be used in Canada; produce four (4) prototypes; and support railway testing of these units for a period of three (3) months. After December 1984 most of the contract work was performed by employees transferred to DSL Dynamic Sciences Limited, which at that time also assumed contract costs exceeding TDC's funding.

A major item required by Canadian National Railway (CN) and Canadian Pacific Railway (CP) is the capability to apply the emergency brake at the rear of the train; the incorporation of this feature necessitated nearly a total redesign of electronic hardware as well as the development of an emergency dump valve. The resulting two-way system is known as Digitair II.

2. ADDED FEATURES

The odometer function was implemented in the Digitair front unit by the addition of a small circuit board to condition the signal from the locomotive's axle alternator, and by software upgrade to provide the conversion from this signal to distance displayed in feet. The odometer is calibrated by the activation of a 'Cal' button at the beginning and end of a measured mile; distance is measured by pressing the 'Dist' button when passing a start point.

To indicate to the head end consistently that the rear car has

started to move, a motion detector was required which would operate over a wide range of accelerations and environmental conditions. Radar motion sensing and a number of other approaches were examined and finally rejected in favour of a custom accelerometer implemented with a piezo-electric wafer. By processing the filtered outputs from this device through a software algorithm residing in the rear unit's processor, moving, stopped, and direction of start indications are sent to and displayed by the front end. Additionally, strong accelerations experienced while the train is moving are interpreted by the algorithm as buffs or drafts, depending on direction.

Compliance with the AAR guidelines was accomplished through software modifications. Most railways are now specifying the AAR protocol for new equipment.

Low power consumption, high brightness, and long bulb lifetime are features strived for in the design of the HVM light. U.S. Federal Railroad Administration (FRA) rules stipulate that this light must flash at approximately one second intervals, and must be either amber or red, and must have at least 100 candela brightness on center. A half-power beamwidth of +/- 5 degrees vertical and +/- 15 degrees horizontal is also required. Such a light was specified, sourced, and integrated with control circuitry and a battery module to form an option to the Digitair rear unit which becomes integral with it when the option replaces the telemetry unit's lid. The light's on/off status is sent to the head end and displayed on the front equipment, so that battery or bulb failure will be evident to the front crew.

The ability to transmit a second pressure was a requirement of some railroads, especially those operating heavy tonnage trains on steep gradients. A second pressure transducer was added to the rear unit and connected to an identical pressure amplifier circuit. By sacrificing the space in the message reserved for 'report count' (used for built-in communication tests), the second pressure is transmitted to the head end simultaneously with the regular pressure. The dual pressure capability is an optional feature and, at time of writing, is being used by one railroad.

3. DIGITAIR II

The Canadian Transport Commission and the Canadian railways required that the telemetry system be able to apply the emergency brakes at the rear of the train on command from the head end. Major additions to the one-way Digitair system to provide this function are components in the rear telemetry unit to dump train air, and circuitry in front and rear equipment for the new front-to-rear communication link. A specification for the new equipment was formulated by the design team and, after revision, approved by CN and CP. The changes from the existing system necessitated nearly a complete redesign of the electronic hardware; the new system is named Digitair II and has a temperature range extending to -45 degrees C.

Initial design of the emergency dump valve was done in-house; design refinement and construction of the prototype valves were contracted out. The dump valve is integral with the attachment to the brake pipe gladhand. It closes on positive pressure, and passes the brake pipe pressure through a hole in its diaphragm to the pressure manifold where the transducer is mounted. The triggering solenoid valve, also mounted in the pressure manifold, vents the manifold on command from the head end thereby unloading one side of the dump valve's diaphragm and causing that valve to open. The high flow exhaust of the brake pipe line through the dump valve is sufficient to activate the emergency brake on the rear car and thence forward along the train.

The new rear unit electronics has, in addition to the features of the one-way system's rear unit, a receiver, the high performance demodulator used in the head end, and a valve driver circuit; the microcomputer has been upgraded to handle the extra workload. The same diecast housing is used with some modification to accommodate the solenoid valve. Internal layout has changed considerably to fit in the additional components. Digitair II's rear unit is named the Sense and Braking Unit (SBU).

Splitting the front equipment into two boxes and changing its architecture somewhat was necessary to stay within the dimensions of the diecast parts of the one-way system. Major items of new design in the front equipment are the 8 W transmitter, a higher capacity power supply, more user interface connections, and here, too, an upgrade of the microcomputer. The receiver, transmitter, and main processor are housed in a unit requiring no user access; it is called the Communications Logic Unit (CLU) and may be installed in a remote location. The operator interacts with the Input and Display Unit (IDU), which is connected to the CLU and may be mounted directly in place of the one-way system's front unit.

Rear-to-front communication protocol remains the same as for the one-way system, and is AAR compatible. The front-to-rear protocol differs considerably to accommodate the conflicting requirements of response time and low battery drain in the rear unit. The bit sync stream front-to-rear is made quite long, and is followed by frame sync and message with repeats. A full repeat of bit sync, frame sync, message is not done (as it is rear-to-front) because of the automatic confirmation cycle which follows any front-to-rear command; a subsequent transmission is sent only when needed.

4. RESULTS

The odometer has been in the field for over a year at time of writing, and is well proven. There have been problems in installations where other equipment was connected to the axle alternator, introducing noise or distorting the signal, but most of these have been overcome.

The motion detector has been tested on many train tests and in field use. The software algorithm has been refined throughout. A number of

problems, such as false stops at low speed on continuously welded rail, have been solved with software change. Others, such as occasional false buffs over switches, remain; certain railways accept the current level of buff/draft performance while others do not. Underway at time of writing is a hardware modification to further improve the reliability of initial direction display when very hard starts are encountered.

AAR compatibility has been tested both in-house and on various railroads. It has been proven further by operation with other manufacturers' front equipment.

The HVM light has been tested to meet FRA requirements by an independent laboratory, and has had over a year of field use.

The dual pressure system has been proven at the Duluth, Missabe, and Iron Range (DM&IR) railway, which currently has 25 units.

Digitair II testing proceeded in the usual phases. Initial prototype checkout and debugging was done in-house during November and December 1985, with more detailed tests occurring in the spring of 1986. The first train test was made in December 1985, followed by longer runs in January, March, April, and May 1986. In icing tests performed in January 1986, it was demonstrated that the valve would stop working only under unnaturally severe conditions. Functional and communication tests on train trips proceeded with improving results throughout the winter and spring 1986, culminating in a run from Surrey, B.C., to Halifax, N.S., on a 6000 ft train, with communication success rates of 98.23% rear-to-front, 98.83% front-to-rear, and an emergency brake response success rate of 100%.

5. CONCLUSIONS

The development of the additional specified items for the Digitair end-of-train telemetry system has been successfully completed. Areas of further work among these items are: standardization of the axle alternator signal provided to the odometer, a job only the railways can undertake; and improvement of the motion detector hardware to provide greater accuracy of start direction during hard starts.

The development of Digitair II, a two-way end-of-train telemetry system capable of applying the emergency brake at the rear of the train on command, has been carried out with excellent results. To date, CN and CP have placed orders totalling 35 systems for testing.

SOMMAIRE

1. INTRODUCTION

En 1984, un système de transmission de données, fiable et performant, appelé Digitair a été réalisé pour informer la locomotive de tête de l'état de marche du dernier wagon. Financé en partie par le Centre de développement des transports (CDT) de Transports Canada, ce système a fait l'objet du rapport TP 6057E, intitulé "End-of-Train Monitoring System", de R.J. Pomeroy, publié en novembre 1984. A l'époque, les chercheurs avaient dégagé certaines fonctions supplémentaires nécessaires pour permettre la mise en service de trains sans wagon de queue. Ces fonctions étaient les suivantes:

- Mesurage de précision de la distance parcourue (odomètre) permettant au conducteur de déterminer le moment exact où le dernier wagon a franchi un point donné: passage à niveau ou aiguillage, par exemple.

- Détection de la rotation des roues du dernier wagon.

- Détection des forces de traction ou de compression s'exerçant sur ce wagon.

- Conformité à la procédure de transmission adoptée par l'Association of American Railroads concernant les dispositifs de surveillance en queue de train.

- Un feu arrière bien visible, intégré au dispositif.

- Suivi, transmission et affichage des valeurs de pression d'un deuxième circuit de freinage.

En juillet 1984, le contractant, Glenayre Electronics Ltd., a donc obtenu du CDT un deuxième contrat pour: mettre au point ces fonctions et, de concert avec les sociétés canadiennes de chemins de fer, écrire les spécifications de ce nouveau matériel destiné au contexte canadien; réaliser un prototype en quatre exemplaires et concourir à leur essai en service pour une période de 3 mois. A partir de décembre 1984, presque toute la recherche a été faite par le personnel technique prêté à la firme DSL Dynamic Sciences Limited qui, à la même époque, avait pris à sa charge les frais dépassant la quote-part du CDT.

Le CN et le CP ayant exigé que ce dispositif soit capable d'actionner le freinage d'urgence à partir du dernier wagon, il a fallu, pour s'y conformer, la réétude presque complète du matériel électronique et l'étude d'une valve vide-vite. Le système bidirectionnel qui en a résulté a été appelé Digitair II.

2. FONCTIONS NOUVELLES

La fonction de mesurage précis de la distance parcourue (odomètre) ajoutée au module avant du Digitair a été obtenue par la mise en place d'un petit circuit imprimé destiné à traiter les signaux émanant de l'alternateur d'essieu de la locomotive et, aussi, par l'adoption d'un logiciel plus puissant devant permettre la conversion de ces signaux en distances et l'affichage de celles-ci en pieds. L'étalonnage de l'odomètre se fait par un bouton CAL actionné juste au début et à la fin d'un parcours ayant exactement un mille de long. Pour l'affichage de la distance parcourue à partir d'un point de repère, il suffit d'appuyer sur le bouton DIST au droit de ce point.

Le détecteur de rotation des roues du dernier wagon exigé par les clients devait pouvoir fonctionner sans interruption dans une large plage d'accélérations et dans toutes sortes de conditions météorologiques. Pour cela, plusieurs procédés ont été examinés, y compris le radar, mais tous ont été rejetés au bénéfice d'un accéléromètre conçu exprès, utilisant un cristal piézoélectrique. Les signaux d'entrée passant après filtrage dans un processeur situé dans le module arrière sont transformés par un algorithme en grandeurs de sortie correspondant aux signaux de mouvement, d'arrêt et de sens de marche du wagon et transmises au module avant qui les affiche. En outre, les fortes accélérations ressenties alors que le train est en mouvement sont indiquées par l'algorithme comme des efforts de compression et de traction, selon leur orientation.

La conformité avec la procédure de transmission de l'AAR a été réalisée par l'adaptation du logiciel. Il est à noter que la majorité des administrations ferroviaires ont adopté cette procédure pour tout matériel neuf dont elles font l'acquisition.

En ce qui concerne le feu arrière, les caractéristiques recherchées ont été: faible consommation, forte intensité lumineuse et longue durée de vie de l'ampoule. La Federal Railroad Administration des Etats-Unis stipule, en effet, que ce feu clignotant à intervalle d'une seconde environ et de couleur jaune ou rouge, doit posséder une intensité lumineuse d'au moins 100 candelas au centre et avoir une ouverture angulaire à mi-puissance de plus ou moins 5^{0} verticalement et plus ou moins 15^{0} horizontalement. Après sa mise au point, ce feu a été intégré à un circuit de commande et à un module d'alimentation, puis offert comme équipement facultatif du module arrière. Il s'installe à la place occupée par le couvercle qui doit normalement recouvrir le boîtier à cet endroit. Enfin, l'état de bon ou de mauvais fonctionnement du feu est transmis à l'avant et affiché à l'intention du personnel de conduite.

L'option de double affichage des pressions de freinage a été exigée par certaines administrations ferroviaires, notamment celles qui exploitent un trafic lourd devant franchir des rampes prononcées. Pour cela, un deuxième capteur de pression a été ajouté au module arrière et relié à un multiplicateur de pression identique au premier, la pression du deuxième circuit de freinage étant alors affichée par le module avant en même temps que celle du premier, dans l'espace auparavant réservé pour afficher le nombre d'essais effectués. Cette option demeure facultative. Au moment d'aller sous presse, elle était utilisée par une société ferroviaire.

3. DIGITAIR II

Une des prescriptions de la Commission canadienne des transports et des sociétés canadiennes de chemins de fer a été que le module arrière du système Digitair puisse actionner le freinage d'urgence sur un signal radio transmis par le module avant. Les principales modifications apportées au système original pour se conformer à cette prescription ont été d'équiper le dernier wagon d'une valve vide-vite et de prévoir les liaisons de transmissions nécessaires. L'équipe d'étude a rédigé la spécification afférente, dont la version révisée a été approuvée par le CN et le CP. Ces modifications ont entraîné une réétude presque complète du matériel électronique, débouchant sur un nouveau système appelé Digitair II, capable de fonctionner malgré des températures pouvant descendre à moins 45°C.

L'étude de la valve vide-vite a été faite initialement par le contractant, alors que l'étude finale et la réalisation du prototype ont été confiées à un sous-traitant. La valve vide-vite est incorporée au raccord rapide de la conduite pneumatique. Fermant sous une pression positive, la valve transmet la pression de l'air comprimé dans la conduite, à travers un trou dans son diaphragme, à un collecteur où est logé le capteur de pression, ainsi que l'électrovalve chargée d'actionner les freins sur un signal du module avant. En mettant le collecteur à la pression atmosphérique, l'électrovalve déleste un côté du diaphragme, causant l'ouverture de la valve vide-vite. Le débit élevé qui caractérise le vide-vite est alors suffisant pour actionner le frein d'urgence du dernier wagon et, de proche en proche, celui des autres wagons.

Le module arrière réétudié comporte, outre les composants originaux, un récepteur, un démodulateur performant qui se trouvait dans le module avant et un circuit commandant la valve vide-vite. Quant au micro-ordinateur pilotant le nouveau système, il a été rendu plus puissant. Le boîtier réalisé par moulage sous pression a été quelque peu modifié pour recevoir l'électrovalve tandis que l'intérieur a été considérablement réaménagé pour faire de la place aux nouveaux composants. Le module arrière est appelé Unité de détection et freinage (UDF).

Il a fallu diviser le module avant en deux boîtiers et modifier quelque peu son architecture afin de respecter les cotes du boîtier original. Le module réétudié comporte maintenant un émetteur 8 W, une alimentation de capacité accrue, un nombre accru de connexions d'interface et un micro-ordinateur plus puissant. L'émetteur-récepteur et le processeur principal sont logés dans un module appelé Logique de communication qui, ne nécessitant aucune intervention humaine, peut être placé hors de vue. L'opérateur communique avec le système au moyen du module Entrée et Affichage relié à la logique de communication et qui, maintenant, occupe la place du module avant de l'ancien système.

La procédure utilisée pour les transmissions de l'arrière vers l'avant reste la même qu'antérieurement, étant conforme à celle de l'AAR. Toutefois, la procédure de transmission de l'avant vers l'arrière a été considérablement modifiée pour concilier deux exigences contradictoires, soit un temps de réponse très court et une faible ponction d'énergie sur la batterie du module arrière. Le train des bits de synchronisation, relativement long, est suivi des bits de verrouillage de trame et du message qui, seul, est répété. La répétition intégrale de toute cette procédure n'est pas nécessaire dans ce cas (contrairement à la transmission de l'arrière à l'avant), vu le cycle de confirmation qui suit automatiquement toute commande émanant du module avant, une retransmission ultérieure n'étant prévue que si elle est nécessaire.

4. RESULTATS

L'odomètre, en service expérimental depuis plus d'un an au moment d'aller sous presse, s'est bien comporté malgré les ennuis éprouvés par suite de l'installation de certains équipements reliés à l'alternateur d'essieu. Le bruit parasite et la déformation des signaux attribuables à ces équipements ont fini par être réglés en grande partie.

Le détecteur de rotation des roues a été soumis à des essais particuliers et des essais en service, l'algorithme correspondant ayant été affiné au fur et à mesure. Certains problèmes, comme les signaux indiquant des arrêts fictifs alors que le train avançait lentement sur des longs rails soudés, ont pu être résolus par des modifications logicielles. D'autres, comme les signaux indiquant un état de compression fictif lorsque le train passe sur des aiguillages, restent encore à résoudre, certaines sociétés ferroviaires ayant accepté les niveaux actuels de performance en compression/traction, mais d'autres les ayant rejetés. Au moment d'aller sous presse, une modification était incorporée au matériel informatique afin de rendre plus fiables les indications de sens de marche lorsque des secousses très brutales sont ressenties au démarrage. Des essais effectués par le contractant et différentes administrations ferroviaires, ainsi que des essais de compatibilité avec des modules avant d'autres fabricants, ont permis de vérifier la conformité du système à la procédure adoptée par l'AAR.

Le feu arrière est en service expérimental depuis plus d'un an, après avoir été éprouvé par un laboratoire indépendant qui a vérifié sa conformité aux exigences de la FRA.

L'option de double affichage des pressions de freinage a été mise à l'épreuve par les sociétés ferroviaires Duluth, Missabe et Iron Range qui disposent actuellement de 25 unités.

Les essais du Digitair II se sont déroulés selon la norme. Les vérifications préliminaires du prototype ont eu lieu en novembre et décembre 1985 et, de façon plus élaborée, au printemps de 1986. Les premiers essais sur train ont été faits en décembre 1985, suivis d'essais prolongés en janvier, mars, avril et mai 1986. Des essais de résistance au givrage faits

en janvier 1986 ont montré que la valve vide-vite fonctionnait bien, à moins de conditions climatiques particulièrement rigoureuses. Des essais dynamiques de fonctionnement et de transmission ont été faits durant l'hiver 1985-1986 et au printemps de 1986, donnant des résultats qui se sont améliorés progressivement. Le dernier essai de la série a été réalisé sur un convoi de 6 000 pieds de longueur entre Surrey, Colombie-Britannique, et Halifax, Nouvelle Ecosse. Les taux de réussite ont été de 98,23 % pour les transmissions arrière-avant, de 98,83% pour celles avant-arrière et de 100 % pour les réponses aux commandes de freinage d'urgence.

5. CONCLUSIONS

L'intégration des nouvelles fonctions exigées du système Digitair II a été menée à bien. Les secteurs nécessitant une recherche plus poussée sont: la st[illegible]ardisation du signal transmis à l'odomètre à partir de l'alternateur d'ess[illegible]eu, cette tâche étant du ressort exclusif des sociétés ferroviaires; et le détecteur de rotation des roues du dernier wagon pour obtenir une plus grande précision des indications sur le sens réel du mouvement lors des démarrages brutaux.

C'est ainsi que s'est terminé avec succès le développement du Digitair II, système de transmission bidirectionnel en queue de train, capable d'effectuer des freinages d'urgence sur une commande émanant de la locomotive. A ce jour, le CN et le CP ont commandé en tout 35 unités dans le but d'en faire l'essai en service expérimental.

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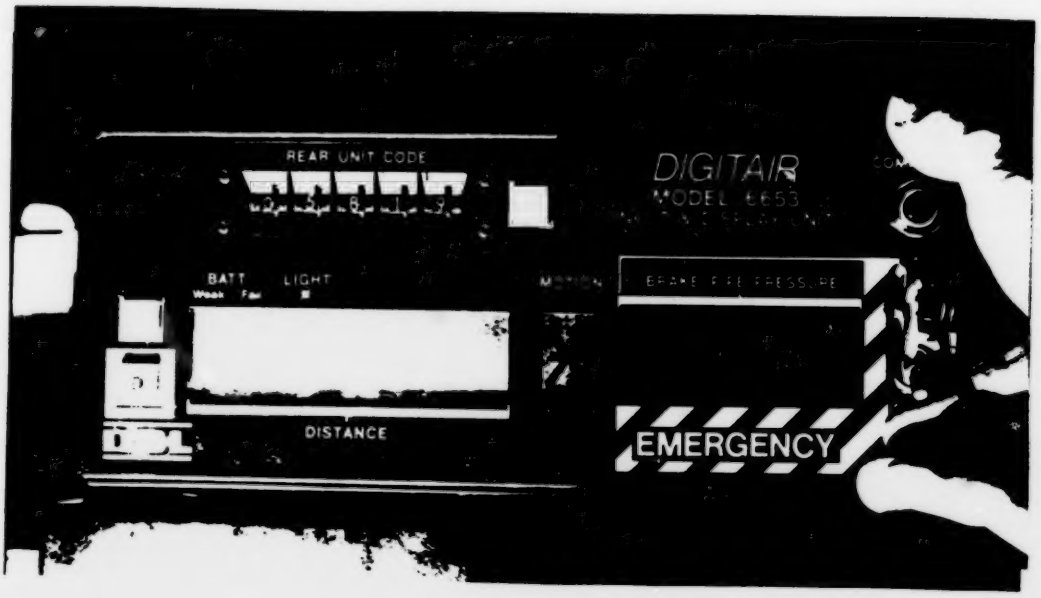
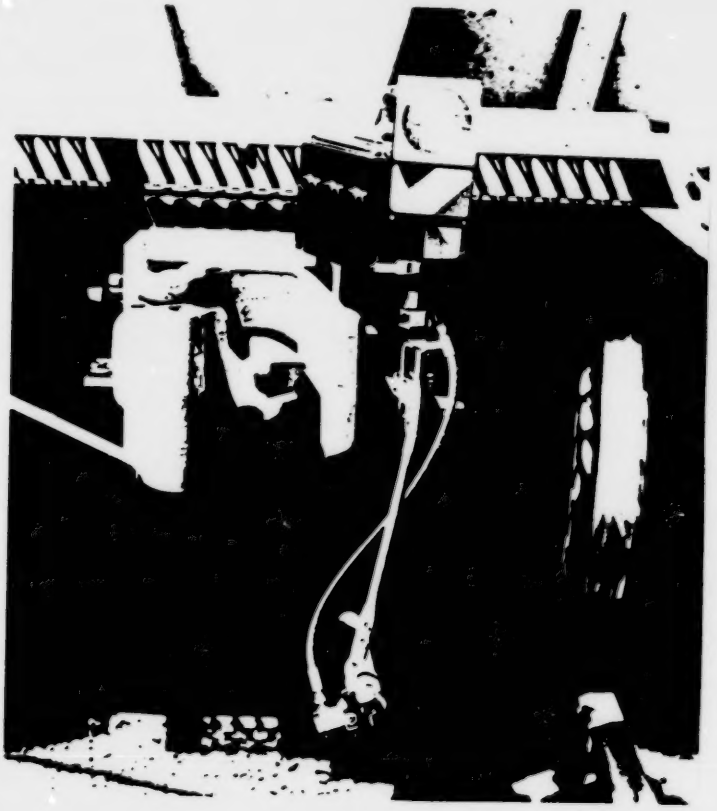

REAR UNIT CODE
DIGITAIR
MODEL 6653
BATT
LIGHT
DISTANCE
EMERGENCY



Digitair II

1. INTRODUCTION

The development of end-of-train telemetry equipment was strongly encouraged, by railroads in both the United States and Canada, at the prospect of their using the equipment in cabooseless train operation. The initial requirement was for simple telemetring of brake pipe pressure from the tail end of the last car, but it was soon recognized that other features were necessary if truly efficient cabooseless train operation were to be realized. This led to the addition of such optional features as:

- distance travelled odometer in the locomotive cab
- rear car motion detector
- rearward facing highly visible marker (HVM) light

One further option, rear-of-train emergency braking initiated from the locomotive, was requested by the Canadian Transport Commission for evaluation in Canada.

1.1 Background

In March 1983 Glenayre Electronics Ltd. was awarded a contract by the Transportation Development Centre for the development, design, construction and testing of an end-of-train monitoring unit. That work was successfully completed in 1984 [1] and led to the development of the Digitair telemetry system which is now widely used in the United States where cabooseless train operation is a widespread practice.

The "Guidelines, Considerations and Radio Frequency Specification for Train Information Systems" prepared by the Association of American Railroads was completed with issue 5 dated December 18, 1984 [2]. This document describes a basic system with 18 options of which five have been generally accepted and used:

Option A, Rear End Marker Device
Option B, Multiple Brake Pipe Pressure Threshold Switches
Option C, Brake Pipe Pressure Transducer
Option D, Rear Car Movement Detector
Option F, Rear Unit Status Monitoring

A sixth option has been incorporated into the Digitair system but is not available from any other manufacturer:

Option G, Rear Car Slack Status

The AAR system with options has become the industry standard to a large extent, with the notable exception of three major U.S. railroads which are using alternative equipment which is incompatible in its communications protocol. Digitair was a strong influence on the AAR system and has in turn included all AAR provisions in its features.

The Federal Railroad Administration (FRA) began the process of modifying certain of its rules pertaining to intermediate terminal air brake testing and rear marker light testing, holding public hearings through the FRA Office of Safety June 5, 1984 and October 23-25, 1985. The result of this process has been a new rulemaking which permits the use of telemetry in the intermediate terminal air brake test. Another rulemaking permitting the use of telemetry in terminal testing of the rear marker light is expected. Both these rules have implications for the design and operational features required in telemetry equipment, and as one rulemaking is not as yet complete, an element of uncertainty remains in defining the system requirements.

In Canada, greater uncertainty exists because the Canadian Transport Commission (CTC) has not yet ruled on the application by Canadian National and Canadian Pacific railroads as to the conditions under which cabooseless trains may operate in Canada. Equipment testing has been asked for and one of the features, the ability to activate emergency braking at the rear of the train, initiated from the locomotive, has been requested by the CTC.

The emergence of a virtually universal requirement for the five optional items listed earlier supported the decision that optimal implementations of these items be incorporated into the basic Digitair system. Special consideration of Canadian needs motivated the development of the rear of train braking (RTB) option for demonstration and evaluation by Canadian Pacific and Canadian National Railroads. This development required that a specification for the RTB option be prepared and signed-off by the parties concerned.

In July 1984, the Transportation Development Centre (TDC) of Transport Canada awarded to Glenayre Electronics Ltd. Contract Number 08SB.T8200-4-4519 for Further Development and Testing of an End-of-Train Monitoring System. In December 1984, DSL Dynamic Sciences Limited of Montreal purchased the rights to Glenayre transportation products, and Glenayre's transportation group became employees of DSL. Subsequent to the sale, all project costs except those paid for by TDC under terms of the contract were borne by DSL.

1.2 Objectives

The objective of this contract, as laid down by the TDC Work Statement, is to develop further the Digitair end-of-train monitoring system to meet the latest requirements of the Association of American Railways (AAR), and of the Canadian railway companies for cabooseless operation.

The detailed statement of work specified the following tasks:

1. To prepare revised specifications for the end-of-train system in accordance with the requirements of Canadian railroads and the guidelines of the AAR.

2. To review the revised specifications with the Canadian railroads and TDC.

3. To carry out the development and implementation of these additional features:

An odometer device to provide an indication to the locomotive driver when the end of his train has cleared switches, crossings, slow order territory, and the like.

A motion detector, to be incorporated into the last car equipment, signalling to the locomotive driver when the last car begins to move, preferably with indication of relative direction of motion.

A device to detect the buffing or drafting status of the tail end of the train when the train is in motion.

Modifications to software and hardware as necessary so that the Digitair product complies with the communication protocol and other requirements of "Guidelines, Considerations, and Radio Frequency Specification for Train Information Systems", third edition, revised Dec 1 1983, as published by the AAR.

A "Highly Visible Marker" light together with necessary electronic controls, protective devices and batteries, as an integral part of the end-of-train device.

The necessary interface to allow the Digitair end-of-train device to be used in railroads having train air lines for retainer braking in addition to the regular air lines.

4. To conduct a study with the objective of optimizing both transmitting and receiving antenna systems for train end-to-end radio data transfer under those conditions that will occur when trains are being operated cabooseless.

5. To procure and/or develop suitable transducers and other hardware as necessary to incorporate the additional features proposed by item 3 above, and to implement the recommendations of the antenna study of item 4.

6. To revise circuit board artwork, silkscreens, etc, to incorporate the features of item 3.

7. To revise system software as necessary to incorporate feature changes and to provide for test and diagnostic facilities.

8. To manufacture four prototypes, each to consist of one front end and one rear end unit together with necessary battery chargers

and/or necessary handheld test sets needed to support the operation of the equipment in the field.

9. To carry out in-plant tests of the equipment.

10. To support testing of the equipment in railway service with several different potential user companies, for a period of 3 months.

Development of an additional feature - end-of-train emergency braking - is covered in part by this contract. Although it is not detailed in item 3 above, it is considered by TDC to be covered by the intent of the contract; it is a definite requirement of the Canadian railways, in particular Canadian National Railway (CN) and Canadian Pacific Railway (CP). Inclusion of the development of this feature greatly increased the scope of the contract while leaving the amount of TDC funding unchanged. At time of writing, Glenayre's contribution to the project has been $60k, DSL's $245k, and TDC's total (at contract termination) $250k.

This report, describing the work carried out and the results achieved, represents the final requirement of the statement of work.

1.3 Outline of Report

Part 2 describes the development of the features of task 3 above; task 5 is covered feature by feature. Part 2 also details the investigation pertaining to task 4.

Part 3 covers tasks 1 and 2, and describes in detail the development of the new telemetry system (Digitair II) capable of initiating an emergency brake application at the last car of a train.

Part 4 describes the procedures used to evaluate the the new features and the results achieved, both in-plant and in railway service.

Part 5 presents conclusions drawn from the foregoing work.

Part 6 offers recommendations for expanded applications of the Digitair system.

It is presumed throughout that the reader has a knowledge of earlier Digitair work supported by TDC. The reader may wish to refer to TDC report TP6057E describing this work [1].

Because Canadian (and U.S.) railways still operate in English units of measure, these are used throughout the report.

2. DEFINED ADDITIONAL FEATURES

2.1 Odometer

2.1.1 Odometer Requirement

The requirement for a distance measuring device came from Canadian and other railways as part of an overall system to replace the caboose. An odometer with a zeroing capability, similar to a trip odometer on an automobile, would allow the locomotive driver to measure how far the head end had travelled past a certain waypoint, e.g. a switch, and therefore know when the tail end was clear of that waypoint.

The following is a list of the main functional requirements of the odometer:

- Signal input is from a standard locomotive axle alternator, 20 or 60 cycles per wheel revolution.
- Optionally, input can be from an optically coupled Bombardier axle sensor, 577.7 pulses per wheel revolution.
- Distance is displayed in feet, up to a maximum of 9999.
- Calibration is possible using a measured mile, to cater for wheel diameters varying between 36 and 42 inches.
- A control exists to start/stop/clear the odometer, and another to start/stop/clear calibration.

2.1.2 Odometer Development

Designing the odometer feature into the existing Digitair system was straightforward, given that the display and control buttons already existed. New hardware was required only to filter and amplify the signal from the axle alternator to digital levels, and to provide different division ratios for the possible input types so that a uniform frequency (pulses per wheel revolution) was output to the front unit's internal microcomputer. The new hardware took the form of a small circuit board (Figure 1) which could be installed in the front unit, and a connector for axle alternator input. Additional software for the front unit completed the implementation of the odometer.

2.1.3 Odometer Description

At low frequencies of axle alternator output, such as those encountered when the locomotive is crawling slowly, amplitude is very low. The input filter has the highest response here; the curve is shown in Figure 2. The input for the Bombardier sensor uses a sensitive high-speed phototransistor type opto-isolator; no filter is required here because the input signal is 10-15 volts digital. The counters on the board are implemented using standard CMOS.

Their are six contacts available to the user on the axle alternator connector: a pair for 20/60 cycle per rev axle alternator input, a pair to

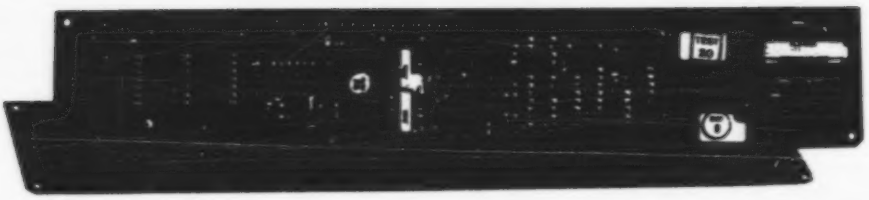


Figure 1 Odometer Board

Without Transformer

With Transformer

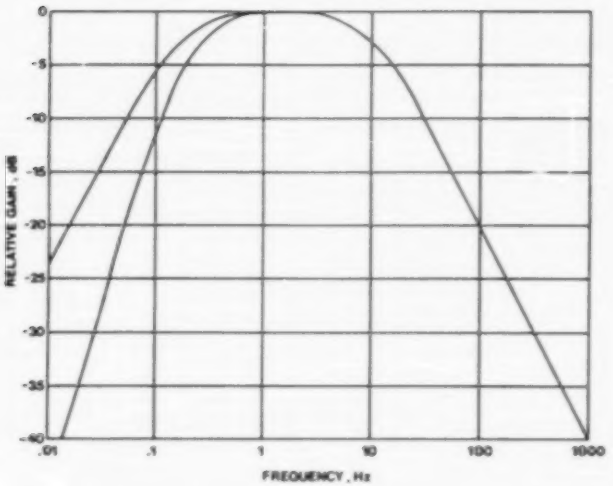


Figure 2 Odometer Filter Response

strap together to enable correct frequency division for 60 cycle per rev axle alternators, and a third pair going to the opto-isolated input that is used for the Bombardier type sensor. Selection of the 577.7 pulse per rev feature must be done by an internal strap.

The functions available to the operator are implemented in software. When the front unit is first powered up, a default calibration corresponding to a 38 inch wheel is assumed. The locomotive driver calibrates by pressing the Cal button at the beginning and again at the end of a measured mile. If the number of wheel revolutions counted in that time corresponds to a wheel diameter of between 36 and 42 inches, that number of wheel revolutions is taken as being one mile; otherwise, the default calibration remains. Distance is measured by pressing the Dist button at the start of measurement, and observing the display. The display can count up to 9999 feet before rollover. The left half of the display is used to display the distance, concealing the battery and marker light status indicators during measurement. A subsequent push of the Dist button freezes the distance measured, and a third push causes the display to revert to showing the usual status indications. If the internal strap which selects display of pressure in kilopascals is installed, metric operation is assumed and the distance is displayed in meters, with calibration distance being one kilometer.

2.1.4 Odometer Design Difficulties

Care was taken in the design of the input stages of the odometer board to ensure immunity to the high noise environment of the locomotive, and indeed locomotive noise posed no problem in the case where an axle alternator alone was connected to the odometer.

The problem cases occurred in locomotives where other equipment was connected to the axle alternator. The most notable of these was found at Chessie in some locomotives that had alerter systems connected to the axle alternator; there it was discovered that this equipment put common-mode AC on the axle alternator, plus common- and differential-mode DC. It would even put differential mode AC on the leads, in the same frequency range as the axle alternator signal, when an external ground fault was present in the locomotive and in the presence of the capacitance to ground found in the Digitair odometer circuit. Adding an isolation transformer at the odometer input reduced the capacitance and got rid of the false signal. DC immunity was also increased, and this change became permanent.

CN found that a certain brand of axle alternator put out a 1 cycle per rev artifact on top of the 60 cycle per rev signal, due to eccentricity in the mounting of the gear used as a magnetic trigger element. This caused the real signal to be swamped at higher speeds due to the response curve of the filter. By removing a capacitor that had been introduced to cater for the alerter situation, the problem could be resolved.

The basic problem in the installation of the odometer in a locomotive is that there is usually a variety of other equipment connected

to the axle alternator, the combination of which varies from locomotive to locomotive. Standardization of the signal provided to the odometer is a problem that only the railways can resolve.

2.2 Motion Detector, including Buff/Draft

2.2.1 Motion Detector Requirement

The function of the motion detector is simply to detect the motion or absence of motion of the rear car, and to report the initial direction of motion. It must operate reliably in all environmental conditions presented by the Canadian climate.

Due to coupler slack action and gradient effects, the motion detector's direction indication cannot be sustained.

2.2.2 Motion Detector Development

A number of different sensing methods were considered to implement the motion detector function.

Those that were eliminated without any experimentation were optical image processing and schemes that involved track contact. Optical imaging would have been expensive in unit hardware cost and in software development, and would have been prone to degradation if the aperture became obscured with ice or dirt. Sensors involving track contact (e.g. a small wheel on the track, with a rotational transducer) would inherently produce unambiguous results from the ideal mechanism, but real devices would likely be fraught with mechanical problems and would not be portable.

Radar sensing was at first very attractive, due to the low cost of commercial units and the fact that it could be integral with the Digitair rear unit. After a number of lab and moving vehicle tests and one train test, this approach was found to have a couple of serious problems. One was that the radar head was difficult to mount in the rear unit housing and to protect from the environment; the other, more serious, was that the inexpensive head could not distinguish between moving terrain and a passing train. A very narrow beamwidth detector (custom and high cost) would have been required to resolve this problem, and even then results would have been doubtful. Also, direction of start would not have been possible with the inexpensive detector.

Inertial detection was the approach settled on after experimentation showed that even very gentle starts could be detected using a piezo-electric wafer in a pendulum assembly. An attempt was also made to use this sensor to detect the buffing and drafting of the last car.

Interfacing this type of sensor to the existing Digitair system was done by filtering the crystal's output into velocity and vibration signals, then digitizing and processing these using the rear unit's microcomputer. The piezo element is relatively inexpensive, but operates

into a very high impedance circuit to achieve its sensitivity, and for this reason is housed with the filter circuit in a nitrogen-filled hermetic can which fits into the rear unit (Figure 3).

The software algorithm to turn the velocity and vibration signals into indications meaningful to the locomotive driver is based on a state diagram which has been formulated and refined empirically from many train tests.

2.2.3 Motion Detector Description

The piezo-electric crystal is glued along each long side into a piece of epoxy fiberglass. A 25 gram lead weight is attached to one of the fiberglass pieces, and the resulting pendulum assembly is suspended from a bracket and angled to correct for the mounting angle of the rear unit on the coupler. Mechanical stops prevent the lead weight from overstressing the crystal during high acceleration. The filter providing the velocity signal peaks about 10 seconds after an abrupt velocity change and decays to the quiescent level in about 20 seconds. The filter for the vibration signal has a peak response at about 3 Hz; the signal output is actually a DC level proportional to vibration. Figure 4 shows the motion detector internal chassis, with pendulum and circuit board.

When the last car is at rest the velocity signal is quiescent at mid-range, and the vibration signal is near supply voltage. The slope of the velocity signal is monitored by the microcomputer, which will transmit a start in the appropriate direction when a certain threshold is exceeded. As soon as the train is moving, the associated vibration starts to lower the DC level of the vibration signal. After ten seconds, the direction of start is replaced by a steady motion indication. At any time, during display of steady motion or initial direction, if the vibration signal rises above a certain level (meaning vibration has dropped off to stopped levels) a stop is transmitted to the head end. In the steady motion state, the microcomputer monitors the velocity signal to look for abrupt changes. If the magnitude and slope of the change exceed certain values a buff or draft is declared, as indicated by the direction of the change.

The motion detector algorithm also caters for the possibility of the rear car being motorized, e.g. carrying a refrigerated truck. Under this condition, the characteristic decay of the velocity signal is the indicator of a stop rather than a lack of vibration; time to declare a stop is increased in this case.

2.2.4 Motion Detector Design Difficulties

Most of the problems encountered in trying to correctly display the movement of the rear car were resolved by changing the software algorithm and adjusting the thresholds in that algorithm. The motion detector software has been refined throughout the duration of the TDC contract.

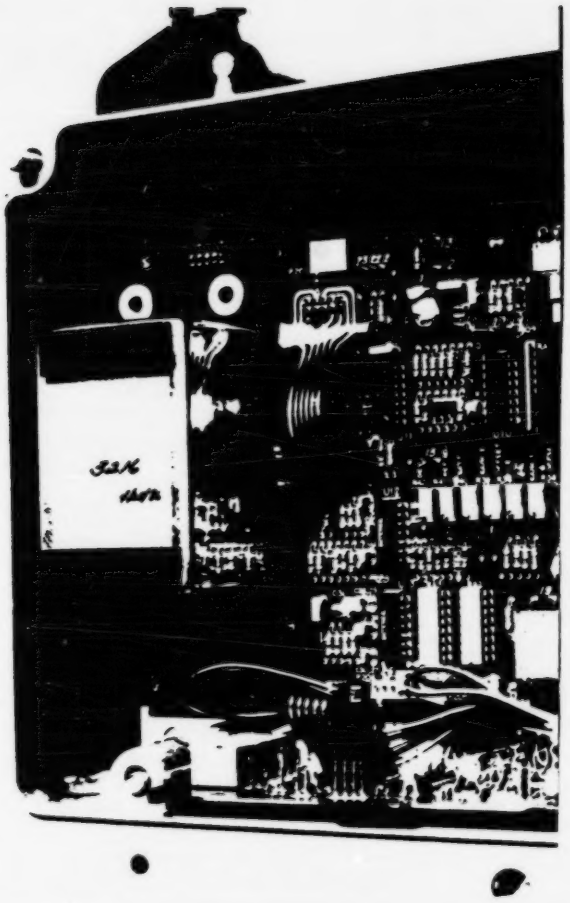


Figure 3 Motion Detector in Rear Unit

Figure 4 Motion Detector without Enclosure

Catering for the possibility of a rear car having a vibration source, e.g. a refrigerator unit, posed some problems in declaring a stop. On a non-motorized car, a stop is declared simply on the absence of vibration above a certain threshold. Since vibration is present on a motorized car, the criterion here is the absence of velocity changes over approximately 50 seconds. False stops resulting from the latter criterion occurred sometimes when trains travelled slowly on continuously welded rail (CWR). The solution involved putting a vibration level window requirement on the motorized car stop, and also disallowing this type of stop altogether if the car was not motorized.

Start sensitivity is a good example of the subjective nature of the motion detector. Testing in Canada had established a certain sensitivity that would always show a start yet never give a false start (a danger if the sensitivity is made too high). The sensitivity had to be adjusted higher three times to satisfy certain U.S. railways.

Buff and Draft indication had even more adjustments in sensitivity to provide the "best" balance between showing hard buffs and drafts while not displaying insignificant ones. A more serious problem, however, was that the motion of the rear car over some curves and switches would cause false buff or draft indication. Because this problem appeared difficult if not impossible to solve, and because the Canadian railways had wisely dropped the Buff/Draft requirement from their specification, a solution was not pursued. At time of writing, some U.S. railways still use the Buff/Draft feature with its limitations, while others now want only initial direction and motion displayed.

Direction of start is indicated correctly more than 90% of the time. It was found that occasionally, on a jerky start, the velocity output moves in the correct direction only a very small amount, then moves in the opposite direction. The software misses the initial direction but detects the opposite (wrong) direction. Sensitivity could not be adjusted further. It was found that additional circuitry connected to the raw crystal output could correctly detect the initial direction on hard starts. This circuitry is now being developed independent of this contract.

A field problem that surfaced several months after production began was cracking of the piezo-electric wafers. Further extensive vibration and shock testing showed that while the design had ample margin to handle the forces experienced on the rear coupler, dropping the rear unit onto a hard surface generated sufficient shock to crack the crystal. Suitable shock mounts were therefore sourced and designed in; these are the four cylindrical objects seen above and below the motion detector in Figure 3.

2.3 AAR Compliance

2.3.1 AAR Requirement

The AAR published two more revisions of its "Guidelines..." for end-of-train telemetry systems since the TDC contract was awarded, and the

latest is considered to be 'final' [2]. It is the document followed for detailed compliance.

2.3.2 AAR Software Development

Compliance with the AAR guidelines necessitated only software changes. The major difference between the existing Glenayre protocol and the new AAR protocol is the message format. Conversion of the ID code from binary coded decimal (BCD) to binary was the biggest change.

Software development proceeded without difficulty, and Digitair now complies fully with the AAR guidelines.

2.4 Highly Visible Marker Light (HVM)

2.4.1 HVM Requirement

The U.S. railways needed a battery operated flashing marker light integral with the telemetry system. The specification for the light is set down by the Federal Railway Administration (FRA) of the United States [3]. The Canadian railways have a similar requirement, although meeting the FRA specification is not necessary for them.

The AAR's goal of 36 hours operation for the rear unit before battery replacement applies also to the HVM light. To meet or exceed this time at the worst case temperatures was an important design target.

2.4.2 HVM Development

Because a market existed in the U.S. for a stand-alone marker light, several U.S. companies were developing suitable lights when this TDC contract began. It was decided therefore to use these companies as suppliers of the light module, and to develop only the control circuitry and battery/light enclosure in-house. A specification was written for procurement of an FRA-approved light.

Star Headlight, of Honneoge NY, and Liteco, of Paterson NJ, are two suppliers whose light is used in the Digitair system. The Liteco unit consumes about half the power of the Starlite, and was used as soon as FRA approval for it was obtained. Preliminary investigations have been made throughout the duration of the contract into other types of light sources, specifically ultra-high brightness LED's and xenon flashtubes. At present both have their cost and/or power limitations.

2.4.3 HVM Description

Figure 5 shows the HVM Light option complete with Liteco light. The diecast battery compartment can hold three Digitair batteries (the same size as that used to power the telemetry electronics), giving a 20 degree C lifetime of 60-70 hours continuous duty. Once the option is installed on the Digitair housing in place of the standard lid, The latches on the battery compartment are interlocked with the telemetry battery compartment

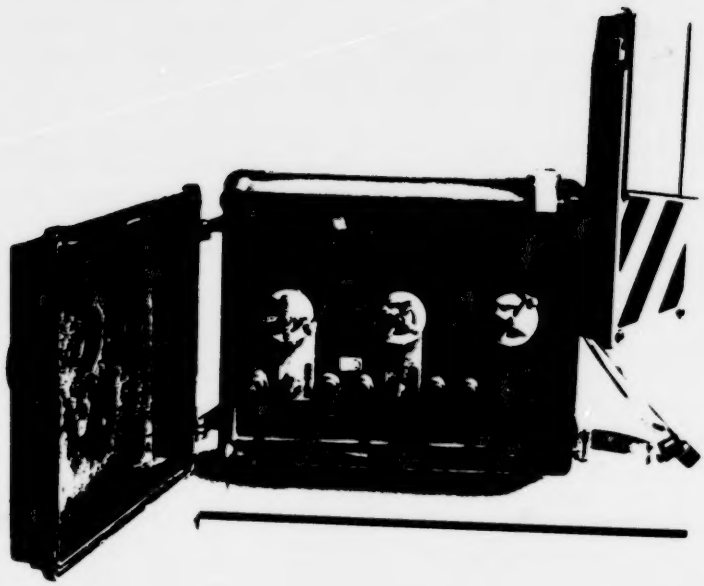


Figure 5 Highly Visible Marker Light Option

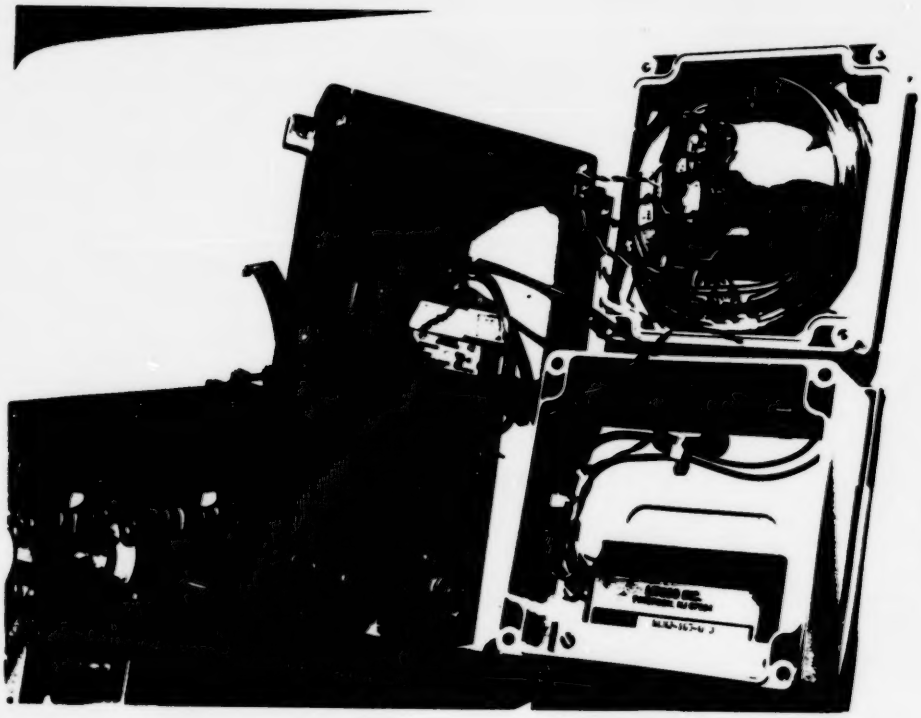


Figure 6 HVM, Internal

so that one padlock may be used to secure the entire system on the end of the train. The "gooseneck" extension houses the control electronics while providing FRA-required track to lamp height. Also mounted in this enclosure is a downward pointing photocell to turn the HVM on and off automatically according to ambient light level.

Figure 6 shows the light disassembled from the gooseneck housing, exposing the control circuit board and the light electronics module. The control circuit board together with the photocell activate the HVM as follows.

- Whenever the telemetry electronics is on, and the HVM software control line is activated, the HVM is on.
- Whenever the the telemetry electronics is off, but brake pipe pressure has been applied at least once since the HVM batteries were installed, the HVM is under photocell control.
- Otherwise, whenever the telemetry electronics is on, the HVM is under photocell control.

Also, the control circuit board isolates the three HVM batteries from each other, cuts out the light whenever the battery voltage falls below 10.4 volts, and provides a signal to the telemetry electronics indicating whether the light is on or off, for whatever reason.

The electronics actually driving the light (in the case of Liteco) comprises a pulse-width modulated current limiter, and a precise flasher to provide an accurate 1.3 second flash period. This is the black potted module seen in the inside of the plastic light box.

2.5 Dual Pressure

2.5.1 Dual Pressure Requirement

Some railroads, particularly those operating heavy tonnage trains over steep gradient territory, use a supplementary direct feed brake system called "retainer air". With this system an independent means of applying train brakes is available, and these railroads desire a tail-end monitor system which can accommodate both air systems.

In the early stages of developing a prototype system for CP Rail, their intention was to monitor both brake pipe and brake cylinder pressure on the last car. As a result, Glenayre's early telemetry equipment allowed for input, transmission and display of up to two pressures from the tail end.

When one potential customer requested telemetry equipment which could monitor their retainer air as well as the standard air, Glenayre were the only supplier in a position to respond; in so doing, the dual pressure option became a permanent feature of Digitair which required optimization and documentation support.

2.5.2 Dual Pressure Description

Because the requirement for the dual pressure system was anticipated

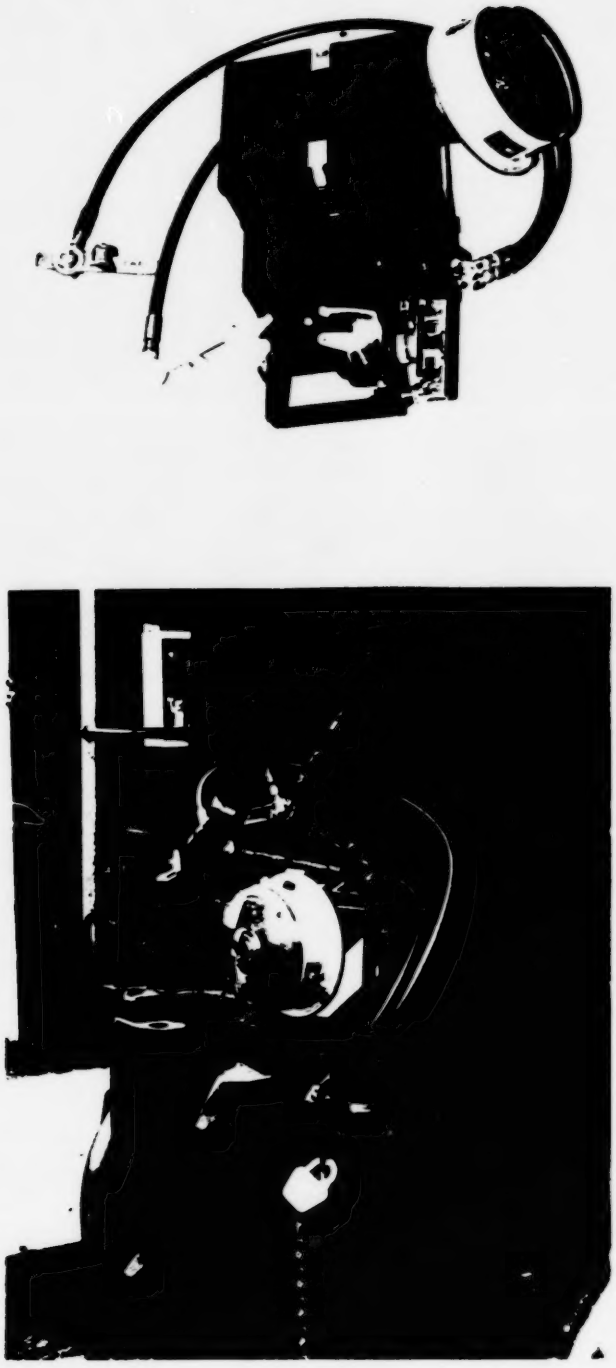


Figure 7 Dual Pressure Rear Unit

when Digitair was being designed, electronic integration of the option was quite simple. A second pressure signal amplifier was already in place, and there was room in the message for the second pressure if the report count (used only during certain test modes) was sacrificed. A jumper on the rear unit digital board selects whether the rear unit is standard or dual pressure.

A second pressure transducer is mounted in a separate housing secured to the outside of the rear unit. The retainer air hose emerges directly from this housing, and the pressure signal from the transducer is fed through the rear unit housing to connect to the telemetry electronics. Figure 7 shows the dual pressure rear unit.

When the rear unit is configured for dual pressure operation, a bit in the message indicates to the front unit that the message contains the second pressure, and the bits that are normally interpreted as report count appear as pressure in the left half of the display.

2.6 Antenna Study

Field experience gained with over one thousand Digitair systems has proven the quarter-wave handle/antenna to be very effective when properly tuned. Radiation pattern measurements were done on this antenna in April 1984 and December 1984 to determine the effect of the presence of the HVM light. Although the pattern did change slightly, the message throughput did not, again confirming that reflection plays the major part in the propagation of this frequency (450-470MHz) from the rear unit to the front antenna.

In February 1985 another transmission success rate test was performed to again verify that the new raised "gooseneck" HVM mounting did not degrade antenna performance. At the same time, a comparison was made between a quarter-wave whip antenna and a Yagi antenna used by a U.S. railway. Both antennas performed well, with no significant difference evidenced between them.

3. DIGITAIR II

3.1 Requirement

By the end of 1984 it was evident that the capability to apply the emergency brake at the end of the train was going to become a requirement for the Canadian railways. At the time, both CN and CP had specifications for a telemetry system including end-of-train braking as an option, but differing to a degree that a common design could not satisfy both [4,5].

After an initial investigation into the tradeoffs involved in two-way communication - response time, battery drain, channel loading, error correction, etc - a specification was compiled and presented to CN and CP in a meeting in Montreal in March 1985. Incorporation of two-way transmission and end-of-train braking necessitated a redesign of both front and rear electronics, and the new system was therefore named Digitair II. All parties agreed to use the specification to define the first sets of equipment to be used for testing; it has had minor revisions since to reflect changes found necessary in the design and initial testing phases. CN and CP have since formulated their own joint specification based on this [6]. Parts of this specification are considered proprietary by the originators.

Compatibility with the AAR format has been maintained in Digitair II. A Digitair II rear unit can communicate rear-to-front with an AAR-compatible standard system, and a Digitair II front unit can receive an AAR-compatible one-way rear unit (but will indicate front-to-rear communications failure).

3.2 Development

A key component of Digitair II is the emergency valve. A preliminary prototype was fabricated from an in-house design in November 1984, and was demonstrated on a stationary train the following month. A patent application for this valve was submitted. Shortly after the overall system specification was agreed upon in March 1985, a detailed design specification for the valve, based on the first prototype, was written and sent to several potential manufacturers for quotation. One manufacturer was selected from these, and delivered refined prototypes in July 1985. Over the same period of time an exhaustive search was made for a suitable triggering solenoid valve which would operate over the full pressure range yet still have reasonable power and space requirements. At one point a custom solenoid valve which would be integral with the rear unit casting was considered, but discarded because of development cost and potential for problems. Finally an off-the-shelf actuator was found which would do the job when mated with a simple custom body designed in-house.

Radio hardware required for two-way communication was also the subject of early investigation. CN and CP specified that the front transmitter be 6dB more powerful than the rear transmitter, i.e. 8W

compared to 2W. After pricing commercially available transmitters in the 10W range, the design team decided that the most cost-effective approach was to use the standard Digitair 2W transmitter and boost the output. Another area of concern was to maintain the required +/-5ppm frequency stability on both the transmitter and receiver in the rear unit over the temperature range of -45 to +70 degrees C. (The one-way system is rated -40 to +70.) The approach taken was to use the resident temperature sensor and microcomputer in the rear unit to provide a correction voltage to varactor diodes added to the transmitter and receiver.

Careful design of the rear unit demodulator allowed the benefits of the demodulator resident in the front unit of the one-way system to be built into the new rear unit, without its associated high current consumption. The CMOS equivalent of the microcomputer used in the one-way system demodulator was selected, and the input circuit was changed to a hard-limiter which takes less current at the expense of about 1dB in overall demodulator performance. With this demodulator now present in the new rear unit, the discrete logic components of the old one-way system modulator could be removed and the function integrated into the new modem. Also, the communication between the host processor and the modem was changed from serial to byte-wide to make software design easier and cleaner. The new modem configuration was used in the new front equipment too, although here the input circuit from the one-way system was kept since power is not a big concern in the front equipment.

With these basic design decisions taken, detailed design specifications were written for the rear unit and the two front units. Detailed hardware design on the rear unit began in May 1985, followed by hardware design of the front units starting in August. Circuit board design started in July and continued until October, followed closely by assembly of the four prototype Digitair II systems beginning in September 1985 and continuing into November.

Software design began as soon as the first detailed design specification was complete, and paralleled the hardware effort in the same order. Changes to modem software was the most demanding task; the goal was to have common software front and rear so that eventually a masked microcomputer, usable front and rear, could be invested in to improve current consumption in the rear. Incorporating installation-selected branches in the already tight code provided a challenge. Software for front and rear host microcomputers, although not as tight, is still real-time code; written entirely in assembly language, it took several months to complete.

System testing began in November 1985, first on the rear unit, then on the front. Intensive effort was put in during November in an attempt to respond to the extreme pressure being applied by the railways to be ready for operational testing by the winter months. However, the new design brought with it a quantity of new design problems which was predictable but not hoped for. First testing of the new system took place at the end of the year, followed by more intermediate tests and the first big test in the CN test car in late January 1986. This test was generally

successful but both the railways and the design team felt that it was premature to call the design complete in view of an unexplained difference between rear-to-front and front-to-rear transmission success rate. February to April 1986 were consumed with detailed in-house testing and modification of the hardware and with improving the communications protocol. A subsequent test run from Vancouver to Halifax in CN's test car in early May proved out the design changes with excellent results.

3.3 Description

3.3.1 General

An important design constraint imposed by the need to keep cost and delivery time minimal was to fit the new design into the diecast enclosures that had been designed for the one-way Digitair system. This was achieved fully in the rear equipment, and partially in the front by packaging the electronics into two enclosures.

The Digitair II rear equipment is, like its predecessor, a single unit which can be carried by one man to the end of the train. Named the Sense and Braking Unit (SBU), it appears different from the older STU only by the presence of the solenoid valve mounted on the housing and the emergency dump valve replacing the simple gladhand connection. With marker light option attached and a full complement of batteries, the SBU's weight is 41 lb compared to the STU's 36.

Because the front electronics had to be split, its architecture was modified so that one box accepts all the wiring from the locomotive and has no user interface, while the other contains the display and all the operator-available switches. The former, named the Communications Logic Unit (CLU), can then be mounted in a convenient remote location while the display unit can directly replace existing one-way system single front units on the control stand.

Figure 8 is a block diagram of the two-way system, and should be referred to when reading sections 3.3.3 to 3.3.5.

3.3.2 Communication Protocol

Rear-to-front communication protocol remains identical to the one-way system, this system having proven very reliable in two years of revenue service. Also, the protocol could not be changed if AAR compatibility was to be preserved.

Front-to-rear protocol was of course free from standardization since no other such system had been built, and has somewhat different design constraints. The conflicting requirements of rear unit battery lifetime (72 hours at -40 degrees C) and a one second response time, determined by the railways to be an acceptable delay, resulted in a 0.6 second long transmission format consisting of a 456 bit sync pattern, followed by frame sync and message with repeats. An entire repeat of bit sync, frame sync, message is unnecessary unless the confirming message from the rear

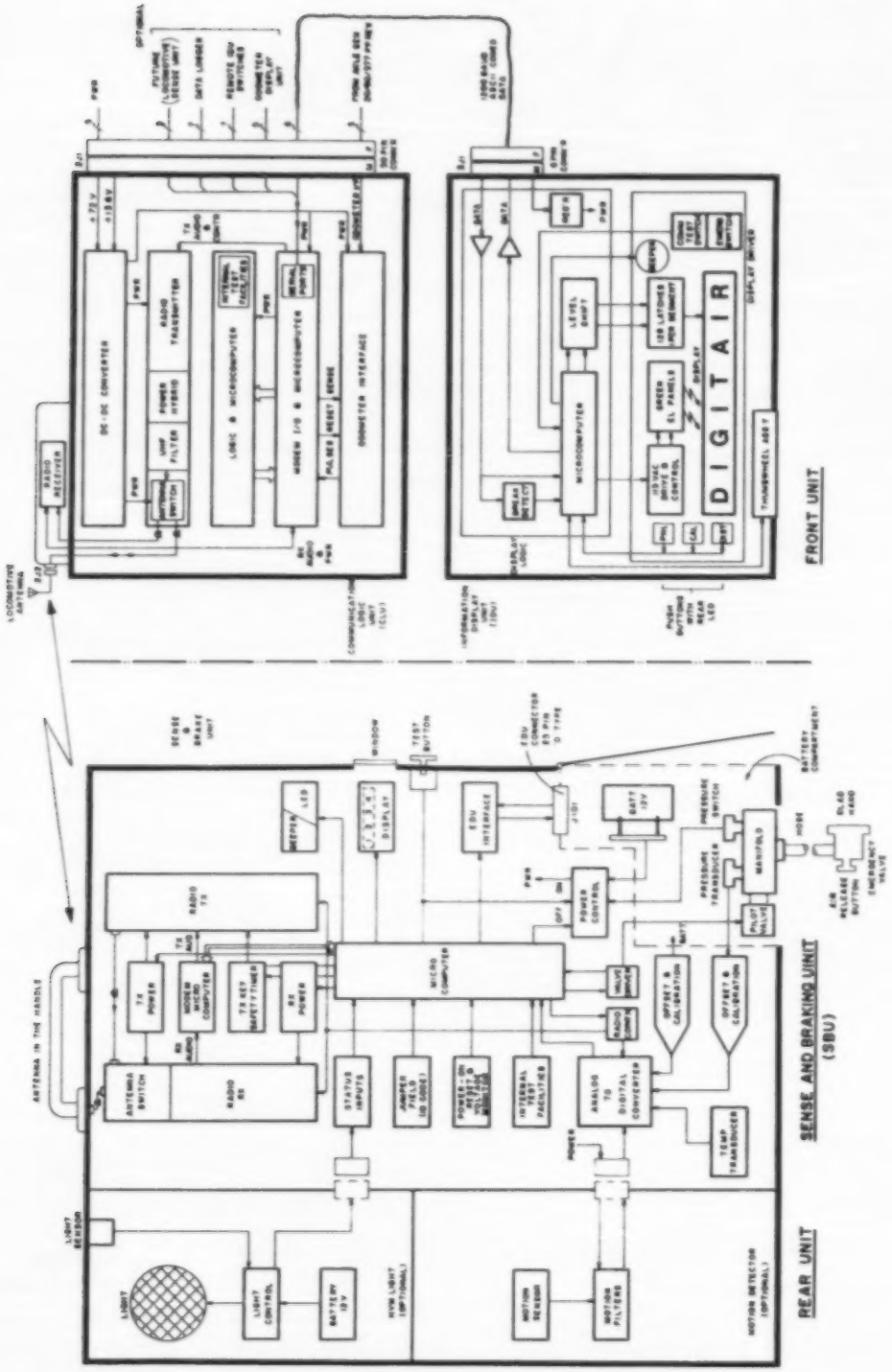


Figure 8 Digitair II Block Diagram

which should immediately follow a command from the front does not come through. Retransmitting only when necessary keeps the demand on the emergency channel down, a significant consideration when two trains in the same vicinity might be trying to apply the emergency brakes at the rear at the same time.

The rules followed for automatic command retransmission are detailed in the system specification and are summarized here. For emergency commands, retries are automatic and spaced as closely as possible, until a confirming message from the rear is received. Thereafter, retries continue on 4 second intervals until the pressure is sensed to have dropped to 0 psig at the rear. All retries cease two minutes after the last Emergency switch activation to avoid channel jamming due to accidental emergency activation by the operator. For status update requests initiated by the Comm Test test button, there are no automatic retries but a visual indication does remain on the display if the confirming message wasn't received. There is also an automatic communication test on 10 minute intervals which allows up to 3 retries spread over 6 minutes.

The type of modulation, logic level assignment, message format, and other communication details for both directions of transmission are all defined in the system specification [6].

3.3.3 Sense and Braking Unit

Figure 9 shows the SBU mounted on a coupler and also "split", exposing the electronics. As stated previously, the external appearance of the unit is very similar to the one-way system rear unit. Internally, however, the layout has changed considerably to accommodate the receiver and associated electronics. The transmitter and receiver are mounted on a power supply circuit board which is attached to the HVM light battery box along with the motion detector. A rugged captive connector mates with its other half when the HVM assembly is secured to the main housing, making all required interconnects except for the antenna cable, which plugs into the receiver directly to minimize loss. The motion detector is shock-mounted using the same rubber mounts as in the one-way system; however end-mounting is used here to accommodate slightly different space restrictions. The board set in the main housing is physically similar to the one-way system, i.e. the digital board secured directly to the housing with the analog board stood-off from it. An improvement is the accessibility of the read-only memory chip (EPROM) for easy software change.

The triggering solenoid valve and the emergency dump valve are shown in Figures 10 and 11 respectively. The dump valve has a large orifice to vent the train's air line when it is activated. When the valve is unpressurized, it is held loosely closed by an internal spring. The valve diaphragm has a small orifice in it to equalize pressure on each side under no-flow conditions. Because the diaphragm area on the downstream (SBU sense hose) side is larger than on the upstream side, increasing brake pipe pressure forces the valve more and more tightly shut. The SBU

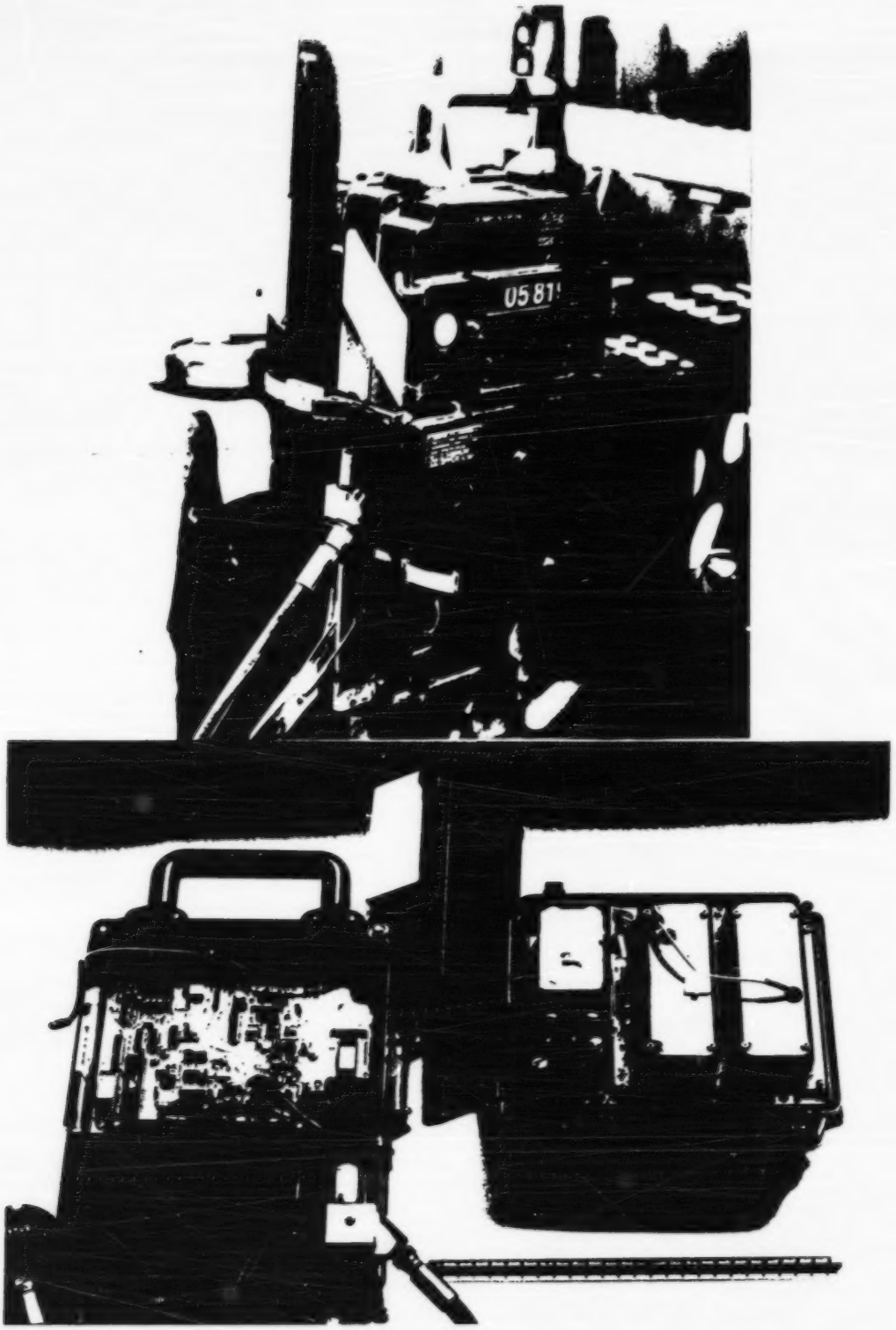


Figure 9 Sense and Braking Unit

Figure 10 Solenoid Valve

Figure 11 Emergency Dump Valve

sense hose is connected to the pressure manifold in the SBU housing, to which is attached the pressure transducer, pressure switch, and solenoid valve. When the solenoid valve is closed, there is no flow in the sense hose and the dump valve stays shut; also the pressure in the manifold equals the pressure at the dump valve inlet and the transducer may accurately read the brake pipe pressure as in the one-way system. If the solenoid valve is opened, sufficient flow occurs to unload the downstream side of the dump valve diaphragm and open the valve, causing a high-flow exhaust of the brake pipe line which initiates emergency activation at the last car and thence forward along the train.

The pressure switch and pressure transducer are unchanged from the one-way system. The pressure switch is used with a very low power discrete CMOS power control circuit to switch on power to the telemetry electronics. The power control circuit, essentially unchanged from the one-way system, shuts the power off on command from the microcomputer.

There are two microcomputers in the rear unit, both 80C31's. One is dedicated as the modem, and the other is a 'host' computer. Any reference to 'microcomputer' in the rear unit implies host microcomputer.

When power is first switched onto the board by the power control circuit, the microcomputer and modem are held reset and the output latches on the board are held in the high impedance state. A voltage monitor chip is used to signal the reset circuit when the logic power is good, and from that time 65 ms elapse until reset is removed from the microcomputer. After another 2 ms, sufficient time to allow the microcomputer to initialize all the latches and its internal memory, hard reset for the modem is released and put under the microcomputer's control, and the latches are enabled.

Digital level inputs to the microcomputer are nearly the same as the one-way system: a jumper field to select the rear unit's ID code, a 4-position dipswitch plus pushbutton to select various test modes, and a number of status input lines. An 8-bit 8-channel analog to digital converter is used to input the analog signals: brake pipe pressure, temperature, battery voltage, and motion signals.

The motion detector is electrically the same as that in the one-way system. The marker light has the features of the one-way system's unit plus a marker light battery sense line.

The (solenoid) valve driver circuit was designed to the railways' guideline that the failsafe mode of the system is to not apply the emergency brakes. The microcomputer is connected directly to this circuit by two output lines and three input lines. An open or short of any single active component in this circuit will not cause the solenoid to be activated and, except for the microcomputer itself, that open or short will be detected and a warning transmitted to the head end. Operation of the valve is not disallowed once the fault is discovered, because depending on the type of fault the circuit may still be able to activate the solenoid.

Other outputs from the microcomputer include the internal beeper and the rear unit display, same as the one-way system. An interface also exists to allow connection of an external hand-held test box (EDU), capable of entering up to 16 different test modes.

The microcomputer is connected to the modem by a bidirectional bus latch, a reset line, a mode line, a power down line, and several timing control lines. The modem is powered up by a pulse on its reset line, and powered down to idle current state by a pulse on the power down line. The state of the mode line when reset is released tells the modem whether to modulate or demodulate. In the modulate mode the microcomputer writes a byte to be transmitted to the bus latch and at the same time sets a 'mailbox' flip-flop. As soon as the modem reads the latch, the flip-flop is reset signalling to the microcomputer that another byte may be sent. A mirror image of this process occurs in the demodulate mode. The demodulator front-end is a hard-limiter or zero-crossing detector; the modulator analog hardware is a simple resistor D/A network, driven by the modem microcomputer through CMOS buffers, plus a low-pass filter.

A separate transmitter and receiver constitute the radio set. A single antenna (in the SBU handle) is used, switched by a PIN diode on the receiver. Both the transmitter and receiver have required frequency stabilities of +/-5ppm; to achieve this an additional high accuracy power supply is used to replace that in the receiver, and both units have added to them varactor diodes for active temperature compensation. The temperature, as read by the microcomputer from the internal temperature transducer, points to a correction voltage value stored in a lookup table. This value is sent to a D/A converter and then applied to the varactor diodes in the receiver and transmitter. The selection of which lookup table to use (receive or transmit) is controlled along with the timing of the receiver and transmitter themselves by the microcomputer. In case of microcomputer fault or operation without a ROM installed, a hardware safety timer ensures that the transmitter can't stay on and jam the channel.

3.3.4 Communications Logic Unit

The CLU is viewed internally from the top and externally from the rear in Figure 12. The receiver and 50-pin connector are mounted on the rear plate. Inside, from rear to front, can be seen the power supply board, the transmitter assembly, the logic board, and the modem-I/O board. The odometer board is hidden beneath the wire harness.

The power supply is a new design, providing 3 amps at 13.6 volts from standard locomotive 72 volt power, compared to the one-way system's 1 amp. It is a switchmode type employing power FET's and operating at approximately 20kHz; care has been taken in its design to provide immunity to the spikes and other noise typically found on locomotive power lines. Provision is also made to accept 13.6 volt power directly from an external source.

As in the SBU, the CLU contains both a host 80C31 microcomputer and

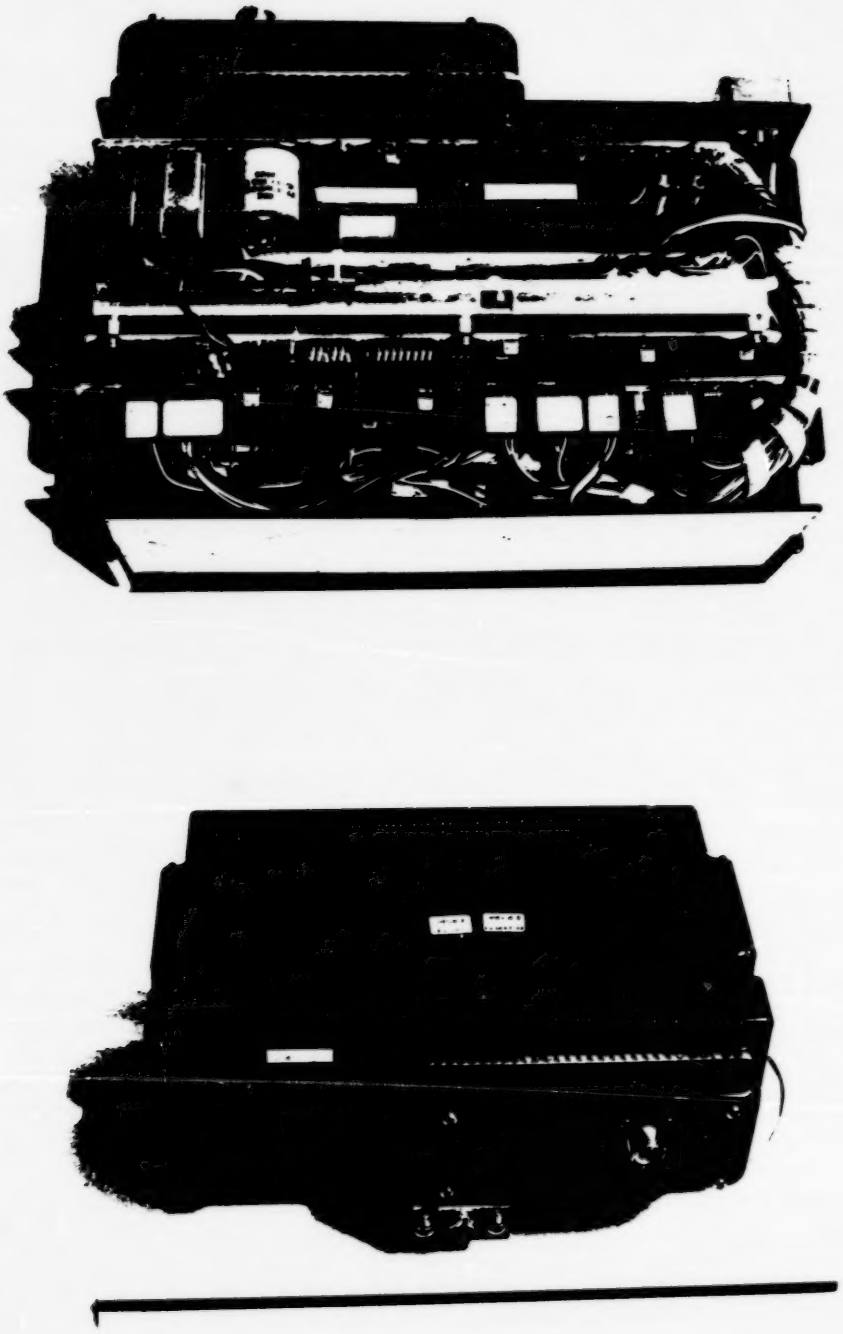


Figure 12 Communications Logic Unit

another dedicated to the modem function; 'microcomputer' in this section will again refer to the host.

Reset circuitry, found on the logic board, is very similar to that used in the SBU. Because there are no output latches in the CLU to worry about, and because the modem's reset line is tied directly to the microcomputer, only the 65 ms delay is necessary. After this time, reset is released from the microcomputer, which then takes software control of the modem.

The CLU has three serial data ports. The IDU and future (optional) Odometer Display Unit (ODU) are interfaced through a dual UART chip. The datalogger port is the only one that may require handshaking lines for proper operation and is implemented with the microcomputer's built-in serial port because it more easily handles these functions. There are two banks of switches on the logic board - one to configure the datalogger port (Baud rate, parity, etc.) and the other to select built-in test functions. Level translators to RS-232 levels for the serial ports are located on the modem-I/O board. Because the IDU and ODU have their grounds isolated from chassis, the level translators buffering these are connected directly to the UART. The datalogger's configuration is unknown, however, and opto-isolators have been inserted between the microcomputer and the datalogger translator to allow breaking any harmful ground loops.

The modem's EPROM contains identical code to the rear unit's modem, and the sections of software applicable to the front unit are branched to conditional on the low level held on one of the modem microcomputer's pins. (The same pin is held high in the rear unit.) As stated previously, this will allow a single masked 80C51 to replace both front and rear modem processor plus EPROM combinations in the future. The modem is connected to the host microcomputer in exactly the same way as in the SBU. The front end of the demodulator is a simple A/D converter, the same as is used on the one-way system; the modulator analog hardware is identical to the rear unit's.

Other inputs provided on the modem-I/O board are for optional externally mounted switches (used instead of those on the IDU), and for a future Locomotive Sense Unit (LSU). The LSU is a device which would transmit the locomotive's brake pipe pressure to the CLU to cause immediate emergency application at the rear on recognition of an emergency application at the front.

The receiver is identical to that of the one-way system. No modification is necessary for frequency stability in the front equipment due to the limited operating temperature range in the locomotive cab. The 2 watt transmitter also requires no modification; however, its output is boosted to 8 watts by an RF power hybrid module. A filter following the booster attenuates spurious emissions below FCC and DOC limits. All transmitter components are enclosed in a UHF-tight enclosure. Output power is fed to an RF relay which, under software control, switches the antenna between the receiver and transmitter. A watchdog timer on the

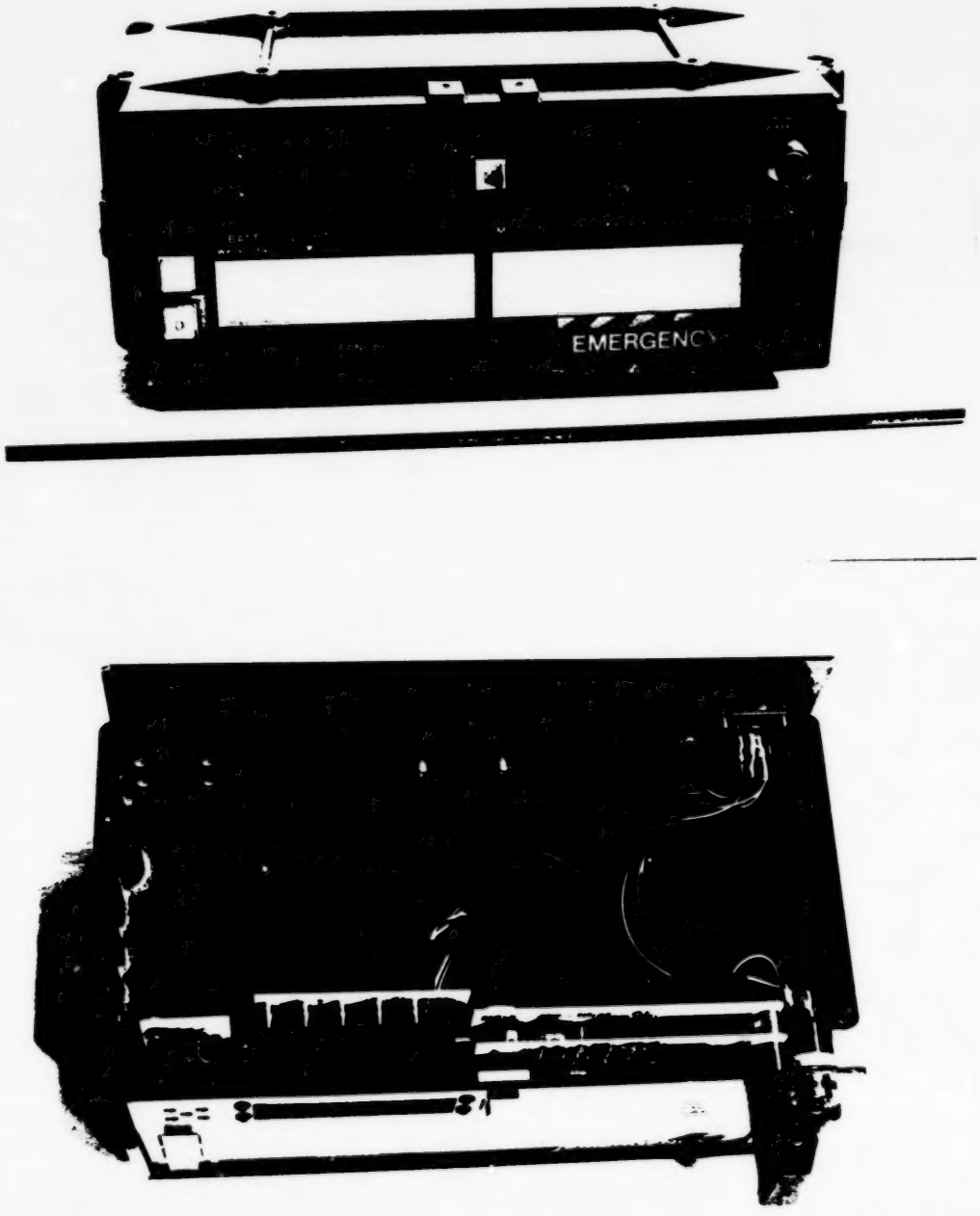


Figure 13 Input and Display Unit

modem-I/O board ensures that the transmitter can't stay on and jam the channel if the microcomputer fails or the CLU is operated without a ROM.

The optional odometer circuit is identical to that described in section 2.1, but the board size has been changed to fit the different width front slot. A new circuit was breadboarded to try to isolate the input circuit from ground using a power transformer rather than an input transformer, but approval of it was not received from the railways.

3.3.5 Input and Display Unit

The IDU is viewed externally from the front and internally from the top in Figure 13. It can be seen that the enclosure for the IDU could be shrunk considerably if so desired. The railways preferred to keep the enclosure identical to the one-way system's front unit, at least for the present, to allow the case to fit onto existing mounting bases.

Rather than connecting directly to the CLU logic board, the thumbwheel switches are connected to the IDU processor board and their settings transmitted serially with other button information. This change from the one-way system was necessary because of the division of the front electronics into two packages. A small circuit board attached directly to the thumbwheel switches and converts their individual BCD outputs to serial format to reduce the number of wires to and also the complexity of the IDU processor board.

The IDU microcomputer has been upgraded from the one-way system's 8048 type display processor to an 8051 type (80C31). This greatly eases implementation of the required serial port for communication with the CLU, and also provides spare processing power for future applications. The IDU microcomputer's main functions are to convert received ASCII characters to corresponding segment information for the display drivers, and to transmit back to the CLU in serial form the status of the IDU switches. Reset of the IDU microcomputer is performed by circuitry monitoring the incoming serial line for a 'break' signal from the CLU. A switch has been added to permit operator adjustment of the electroluminescent backlighting of the display. This switch is read by the IDU microcomputer which then sends pulses to circuitry on the display driver board to increment the brightness up or down.

The display itself is identical to the one-way system: two custom 4-character liquid crystal displays, back-lit by electroluminescent panels. The driver board uses two octal latches per character, as before, and has the added control circuit for backlighting.

4. RESULTS

4.1 Odometer

Lab testing of the odometer was easily accomplished by using a function generator to simulate the output of the different types of axle alternators and then checking that the correct calculated distance was displayed after a certain time.

During troubleshooting of the noise problems on the odometer, the best quick test for proper functioning of the feature was to do a number of distance measurements on a locomotive, between two markers spaced several hundred feet apart. Repeatability of +/- 2 ft was the objective; +/- 1 ft over 200 ft was obtained in Chessie's yard in Cumberland MD after circuit modifications.

Testing on Canadian railways has consisted of calibrating the unit over a measured mile then taking readings on other measured sections of track. Results have always been good except on 'problem' locomotives. Generally, if there is an installation or noise problem, poor odometer behaviour is soon evident.

4.2 Motion Detector

All functional testing of the motion detector had to be done on trains due to the empirical way the crystal's output is translated to display indications, and because of a lack of quantitative measurements of acceleration of the rear coupler in normal train operations.

The typical test run involved installing a rear unit on the rear coupler of a caboose and monitoring the motion indications displayed on a front unit inside the caboose. A cable was run from the rear unit to a strip chart recorder to record velocity and vibration signals from the motion detector module and compare them against motion indications on the front unit.

Table 1 summarizes train tests performed throughout the duration of the contract to assess motion detector performance.

4.3 AAR Compliance

The requirements for AAR compliance are well detailed by the guidelines. In-house software verification constituted most of the testing; motion detector train tests using AAR protocol software served as field verification. Since then AAR compatibility has been further confirmed in operations on the Atchison, Topeka and Santa Fe Railway, and others, who operate some trains with the Digitair rear unit and another manufacturer's front unit.

Table 1 Motion Detector Train Tests

Date	Rwy	Route	Features	Observations
13Jul84	BCR	North Vancouver BC - Lilloet BC	F,R,M,S,B,D	Generally OK
8Sep84	BCR	North Vancouver BC - Squamish BC	F,R,M,S,B,D	Some wrong directions and false stops
10ct84	CN	Surrey BC - Winnipeg MB	F,R,M,S,B,D	False stops on CWR
28Jan85	BCR	North Vancouver BC - Squamish BC	F,R,M,S,B,D	False stop, false buff and draft indications
29Jan85	BCR	North Vancouver BC - Squamish BC	F,R,M,S,B,D	Generally OK
7Mar85	CN	Surrey BC - Chilliwack BC, rtn	F,R,M,S,B,D	False buffs and drafts, false stop
21Mar85	CN	Surrey BC - Chilliwack BC, rtn	F,R,M,S,B,D	False buffs
17Apr85	CSX	Cumberland, MD - Harper's Ferry, MD	F,R,M,S,B,D	False and missed buffs and drafts.
12Jun85	CR	Altoona PA - Chicago IL rtn	F,R,M,S,B,D	False and missed buffs and drafts, wrong dir'n
9Jul85	CN	Surrey BC - Vancouver BC	F,R,M,S,B,D	Shock mounting checked out OK
13Aug85	CN	Surrey BC - Chilliwack BC rtn	M,S only	All indications correct
4Sep85	CN	Surrey BC - Kamloops BC	M,S only	All indications correct
5Sep85	CN	Kamloops BC - Edmonton AB	F,R,M,S,B,D	False and missed buffs and drafts
6Sep85	CN	Edmonton AB - Saskatoon SK	F,R,M,S,B,D	False and missed buffs and drafts, and wrong dir'n
7Sep85	CN	Saskatoon SK - Winnipeg MB	M,S only	All indications correct
6Feb86	CN	Surrey BC - Chilliwack BC, rtn	F,R,M,S,+NH	All indications correct
13Feb86	CSX	Cumberland MD - Martinsburg WV	F,R,M,S,+NH	Some wrong dir'n indications
14Feb86	CSX	Cumberland MD - Bloomington MD	F,R,M,S,+NH	Wrong dir'ns and false stops
17Apr86	CN	Surrey BC - Boston Bar BC	F,R,M,S,+NH	False stop
1May86	CSX	Cumberland MD - Martinsburg WV	F,R,M,S,+NH	All indications correct
5May86	CR	Harrisburg PA - Reading PA	F,R,M,S,+NH	All indications correct
17Jun86	CN	Surrey BC - Chilliwack BC, rtn	F,R,M,S,+NH	Software bug
30Jun86	CN	Surrey BC - Chilliwack BC, rtn	F,R,M,S,+NH	All indications correct

F=forward R=reverse M=motion S=stop B=buff D=draft NH=new hardware

4.4 HVM Light

Testing of the HVM light to assure it met FRA requirements was performed for the manufacturer (Liteco) by ETL Testing Laboratories Inc, Cortland NY [7]. In-house testing consisted of checks to ensure compatibility of the light and control circuit, and environmental tests.

Temperature tests showed that the Liteco light's current drain gives a battery life of at least 60 hours continuous operation at 20 degrees C, and at least 25 hours at -40 degrees C. Vibration tests proved it could withstand operation on the rear coupler.

4.5 Dual Pressure

The components for the second pressure in the dual pressure option rear unit are nearly identical to the first pressure, and therefore no extensive testing was done apart from in-house verification that pressure applied to the second gladhand connection was measured, transmitted, and displayed correctly. The system has been field proven at the Duluth, Missabe, and Iron Range railway, who have 25 units at time of writing.

4.6 Digitair II

Testing of Digitair II formed a major portion of the developmental effort. The following areas were covered:

- Valve testing
- In-house hardware and software verification
- Environmental testing
- In-house communication testing
- Over-the-road communication testing and evaluation of new features related to end-of-train braking.

The prototype dump valves were proven to operate over a pressure range greater than 20 psig to 125 psig, would seal at less than 2 psig, and, when triggered, would stay open at any pressure greater than 2 psig. Each one was also tested to 200 psig without damage. Temperature testing proved the valve worked at -45 degrees C and +70 degrees C.

All train tests of the valve under normal operating conditions went without problem. Tests were conducted in Winnipeg by CN in January 1986 to test the valve's susceptibility to icing. At an ambient temperature of -15 degrees C snow was packed into the valve orifice, then water added on the surface of the snow and allowed to freeze. The snow plug was blown clear immediately on activation; air pressure was 65 psig. The same test was tried again, but this time the snow was saturated with water and allowed to stand overnight; the valve failed to operate the following morning. In general, it was felt by CN that the valve's immunity to clogging was quite good.

Some effort was spent in getting the design of the solenoid valve finalized. Testing determined that while a solenoid valve seat diameter of 1/8" was sufficient to operate the dump valve, 5/32" gave much quicker

response and provided a greater margin of safety. Given this required diameter, maximum operating pressure had to be traded off against coil power (and size) requirements. Refinement of valve seat design enhanced the performance of the valve and the final configuration was tested to pull the valve open at 140 psig.

In the icing tests in Winnipeg the solenoid valve exhaust port was packed with snow and ice in the same manner as the dump valve, and cleared every time due to the flexing of the protective sheet metal cover over the valve.

Hardware and software debugging and verification of the prototype units was intensive From November 1985 to January 1986, and continued after that at a steady pace with careful testing until May 1986.

Careful environmental testing was also performed during February to April 1986. Performance of the front and rear units, and especially their receivers and transmitters, was checked at 15 to 20 degree C intervals over their respective operating temperature ranges. Several refinements had to be made before successful runs were completed. Vibration and shock testing was performed on one system and was successful on the first run, due mainly to the packaging experience gained with the one-way system.

In-house communication testing consisted mostly of low signal level bit error rate (BER) tests on the new front and rear modems, in comparison to the time-proven demodulator in the front unit of the one-way system. As expected, the new CLU demodulator is identical in performance to the one-way system's; this really served as a double check that interconnect changes to the host microcomputer and software changes which should have had no effect on performance actually didn't. The rear unit demodulator with the hard limited input performed 1dB worse than the front unit's, as predicted by theory.

The first train test of the new system was on the Chilliwack switcher (CN) in mid-December 1985, and really only ensured there were no big surprises. The next test was in Winnipeg in early January on a 6000 ft train, and generally confirmed performance, although no statistical measurements were taken. A short 20 car train was put into emergency three times at 20 mph in Symington yard, Winnipeg, using the new system. Then on January 20 the first major test began from CN's Thornton yard in Surrey, BC on their test car, and proceeded as far as Saskatoon. It became increasingly evident that rear-to-front communication performance was very poor (about 60%) and on-board troubleshooting equipment was insufficient to uncover the problem. The test was stopped at Saskatoon, and resumed at Winnipeg several days later when the equipment was returned with a software bug fixed. The bug manifested itself only when the odometer was used; communications and odometer function had previously both been tested independently but never together. The test resumed on a run from Winnipeg to Edmonton. Rear-to-front performance (measured by built-in test software) matched previous one-way system tests (98-100%), but front-to-rear appeared to be about 2% worse. Since this difference was somewhat surprising, it was decided to halt the test and spend the

needed time to analyze the problem.

The performance discrepancy was evident only when comparing front-to-rear Comm Test transmissions to rear-to-front transmissions. Because automatic repeats are generated as required when front-to-rear transmissions are due to Emergency switch activation, emergency and simulated emergency application attempts were always 100% successful. (The rear units under test were modified with a relay wired in place of the solenoid valve. The contacts of the relay shorted out the pressure signal in the rear unit, causing 0 psig to be transmitted as long as the relay was activated. This arrangement made a good simulated emergency test.)

No single cause was found for the poorer performance front-to-rear. During February to April 1986 several hardware faults and a couple of timing problems were uncovered which could have at least partially explained the results, but fixing them effected only marginal improvement. Then the frame sync and message error correction were made more powerful, until front-to-rear success rates approached rear-to-front. The appendix describes in detail a built-in test, formulated in April, to simultaneously accumulate rear-to-front and front-to-rear statistics. This provides much more data on a given train trip, and gives a more accurate comparison of these two groups of statistics than previously available. With several train tests between Thornton yard and Kamloops on 6000 ft trains showing increasing improvement, another major test was planned from Vancouver to Halifax on CN's test car in early May 1986. This proved very successful and, pending the railways' approval, sufficient to freeze the design.

Table 2 lists Digitair II train tests performed to date, and the results obtained.

Table 2 Digitair II Train Tests

Date	Route	Train Length	Comments	Success Rate,% R - F	F - R
20Dec85	Surrey BC - Hope BC rtn	800'	Generally satisfactory despite known bugs	--	--
12Jan86	Winnipeg MB (Symington yd)	--	Valve icing tests OK	--	--
13Jan86	Winnipeg MB (Symington yd)	1000'	Applied emergency brake 3 times from 20 mph	--	--
13Jan86	Winnipeg MB - Rivers MB	6000'	First run on long train, CLU battery powered	--	96
20-23 Jan86	Surrey BC - Saskatoon SK	6000'	Installed in fully wired locomotive	60	--
27-30 Jan86	Winnipeg MB - Surrey BC	6000'	After software bug fixed	99.56	98.57
11Mar86	Surrey BC - Kamloops BC	6000'	With other hardware and software bugs fixed	99.75	97.72
10Apr86	Surrey BC - Kamloops BC	6000'	With better frame sync, and using test mode 15	98.39	97.22
30Apr86	Surrey BC - Kamloops BC	6000'	Further protocol changes, and using test mode 15	98.64	97.58
6-15 May86	Surrey BC - Halifax NS	6000' avg	Successful cross-Canada test; Overall rates:	98.23	98.83
9May86	Melville SK - Winnipeg MB	6000'	Part of cross-Canada test, using test mode 15	99.98	99.60

5. CONCLUSIONS

Development of the Highly Visible Marker light, AAR compatibility, and the dual pressure one-way system is now successfully concluded. All of these features are now standard production items.

The odometer is also successfully finished; however, each railway seems to have different combinations of interface problems, due entirely to other pieces of equipment being connected to the axle alternator. Because there are many such combinations within even a single railway, the interface problem remains one only the customer can resolve.

The motion detector in its present state as developed under this contract appears to be satisfactory for some railways and not adequate for others. Work continues in improving the operational acceptability of indication from this device. Implementation of a buff/draft detector using this device has met with very limited success; use of this feature is not recommended.

Development of the new two-way telemetry system incorporating end-of-train emergency braking, Digitair II, has been entirely successful. At time of writing 35 of these systems have been sold to Canadian railways and are being manufactured. Remaining problems are anticipated to be production related only, barring any change in the railways' requirements.

6. FUTURE DEVELOPMENT

Motion detector improvements are underway and it is anticipated that the hardware modification which is part of the improvement will be in production by September 1986.

A proposal has been submitted to CN and CP to upgrade the two-way built-in communication test so that all data is available at the head end, and to provide suitable output on the datalogger port to record normal operation and statistics with time and mileage tags.

The Odometer Display Unit is nearly identical in hardware to the IDU, and would require only software development to introduce a 'countdown' type odometer where the train length is preset on the thumbwheel switches. An accurate speedometer could also be built into this unit, which could be mounted in locations usually selected for locomotive speedometers.

The Locomotive Sense Unit, a pressure sensing device to detect emergency application at the head end, remains to be developed if the railways require it.

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APPENDIX SYSTEM COMMUNICATION TEST

Instructions for Use

This test provides simultaneous gathering of rear-to-front and front-to-rear communications statistics.

1. Put the SBU in test mode 15 and see [SYSTEM COMM TEST] displayed

2. Put the CLU in test mode 15 and see [SYS COM] displayed

3. To start the test, press the CLU COMM TEST button once. Rear-to-front statistics are displayed on the CLU and can be scrolled through by pressing the DIST button. Front-to-rear statistics are displayed on the SBU EDU and can be cycled through by pressing the EDU TEST button.

   While the test is running, the SBU transmits every 1.92 seconds, regardless of status changes or incoming CLU messages. When the SBU receives a good or correctable message from the CLU, the confirmation bit is sent on the next scheduled transmission.

   The CLU transmits between 200 and 700 ms after receiving a message from the SBU. If no SBU transmission is received, the CLU transmits 1.92 seconds after its last transmission.

4. To terminate the test, press the CLU COMM TEST button. A final front-to-rear transmission is then made, and when a good or correctable double message is received from the SBU, the statistics are frozen, and a beep is sounded.

5. To start the test again, power the SBU down then up, and put it back into test mode 15. Then, simply press the CLU COMM TEST button. This zeroes the rear-to-front statistics and starts the front-to-rear transmissions.

Front-to-Rear Statistics (Displayed on the SBU EDU)

RG = Number of messages that contained no errors.
RC = Number of messages that contained 1 to 4 errors.
RF = Number of messages that contained more than 4 errors.
RSO = Number of messages where bit sync was acquired, but not frame sync.
M1C+M2C = Number of messages with 1 and 2 bit errors.
M3C+M4C = Number of messages with 3 and 4 bit errors.
RNS = Number of messages where bit sync was not acquired. Must be calculated:

RNS = RTX - (RG + RC + RF + RSO), where
RTX is the number of CLU Transmissions

All of the above statistics count to 255 before they wrap around to zero. Therefore, a final count of 100, where there have been three wrap arounds, is really equal to

255	+	256	+	256	+	101	= 868
(1 to 255)		(0 to 255)		(0 to 255)		(0 to 100)	

Front to rear throughput = (RG + RC) / RTX x 100%

Rear-to-Front Statistics (Displayed on the CLU)

RTX	=	Number of reports transmitted (based on the report count)
M1C	=	Number of messages where the BCH was corrected for 1 bit errors
M2C	=	Number of messages where the BCH was corrected for 2 bit (adjacent) errors
MID	=	Number of messages received with the wrong ID
RGG	=	Number of reports 'good-good', i.e. both messages were error free
RCG	=	Number of reports 'corrected-good', i.e. the first message was error free, the second corrected
RGC	=	Number of reports 'good-corrected'
RCC	=	Number of reports 'corrected-corrected'
RGF	=	Number of reports 'good-fail', i.e. one message was error free, the other not correctable. Note that the RLU does not know which message failed (the second or the first).
RCF	=	Number of reports 'corrected-fail'.
RFF	=	Number of reports 'fail-fail', i.e. no report with the appropriate count was received.
TG	=	Number of reports with the confirmation bit set
TF	=	Number of reports without the confirmation bit set

All of the above statistics count to 9999 before they wrap around to zero.

Rear-to-front Throughput = (RTX - RFF) / RTX x 100%

If there is no one in the caboose to record front to rear statistics, a biased front to rear throughput can be calculated : TG / (TG + TF) x 100%. This value is biased because the TG + TF counts are obtained only when rear to front transmissions are good.